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Technical Report

# MODIFIED T-5 BARRACKS — CONTROLLED CLIMATIC HEATING STUDIES

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U. S. NAVAL CIVIL ENGINEERING LABORATORY

Port Hueneme, California

MODIFIED T-5 BARRACKS — CONTROLLED CLIMATIC HEATING STUDIES

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by

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ABSTRACT

This report presents the results of controlled climatic heating studies conducted on the Modified T-5 Barracks developed for polar use. The studies encompassed three areas of investigation:

1. Heat-loss and heat-transfer analyses of the structural shell using electric heat sources and forced convection, and a thermodynamic evaluation of two different ceiling materials.

2. Evaluation of the radiant hot-air floor plenum heating system designed by the Army Engineer Research and Development Laboratories.

3. Evaluation of the overhead duct hot-air heating, ventilation, and humidification system for use in the NCEL-developed temporary polar camp.

The results of these studies show the heat loss from the 28 x 56-foot building to be 96,500 Btuh at an outside temperature of -50 F and 56,500 Btuh at 0 F, indicating an overall heat loss from conduction and infiltration of 0.158 Btuh/sq ft/°F. At these temperatures, a 1-inch acoustical fiberglas drop ceiling reduced the heat loss to 71,000 and 45,500 Btuh, or 26 and 19.5 percent, respectively.

The floor plenum system produced very low levels of air stratification and excellent heat distribution in an unpartitioned building; however, the design does not permit regulation of air temperatures in partitioned rooms. Because of this and other shortcomings brought out in this report, the system is not recommended for use.

The overhead duct system as tested produced moderately high levels of air stratification at -50 F outside temperature but was satisfactory in other respects. Humidity of 20 to 25 percent and ventilation rates of 2-1/2 air changes per hour were maintained without condensation problems. Stratification can be reduced by increasing register discharge velocities for better air mixing and distribution.

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## PART I. INTRODUCTION

Conditioning air in habited buildings for human comfort is probably more difficult in polar regions than in any other area. The extremely low temperatures, low humidity ratio, and use of prefabricated buildings and lightweight materials contribute to the problem. In an effort to improve personnel comfort, heat-loss studies of the Modified T-5 Barracks, developed for polar use, were conducted and two experimental heating systems were designed, fabricated, and tested. One, designed by the U. S. Army Engineer Research and Development Laboratories[1] and fabricated by the U. S. Coast Guard at Curtis Bay, Maryland, is a hot-air floor plenum heating system providing both radiant and convection heating. The other is a complete air-conditioning system incorporating heating, humidification, and fresh-air ventilation. This system was designed under NCEL sponsorship for a packaged temporary polar camp developed by the Laboratory.[2]

This report presents the results of the heat-loss study and the evaluation of the two heating systems. Tests were performed under controlled climatic conditions at the Climatic Laboratory, Pacific Missile Range, Point Mugu, California, during October and November 1962.

### MODIFIED T-5 BARRACKS

The Modified T-5 Barracks, Figure 1, is a 28 x 56-foot building with 10-foot-high walls. It is assembled from 4-foot modular panels. The barracks is a modification of the standard 20 x 48 x 8-foot T-5 building and differs primarily in dimension, floor panel arrangement, and the use of steel rather than wood trusses. The modified barracks was originated by the Bureau of Yards and Docks and designed by the U. S. Army Engineer Research and Development Laboratories.[1] The purpose of the modification was to provide a building of greater width and ceiling height which could be partitioned into more habitable quarters. If successful, the building would be used as the basic structure for temporary polar camps.

Structural tests, performed by USAERDL at the U. S. Coast Guard Yard, Curtis Bay, Maryland,[1] and erection studies performed by the U. S. Naval Civil Engineering Laboratory in California[3] showed the building to be of suitable design, meeting the requirements set forth by the Bureau of Yards and Docks.

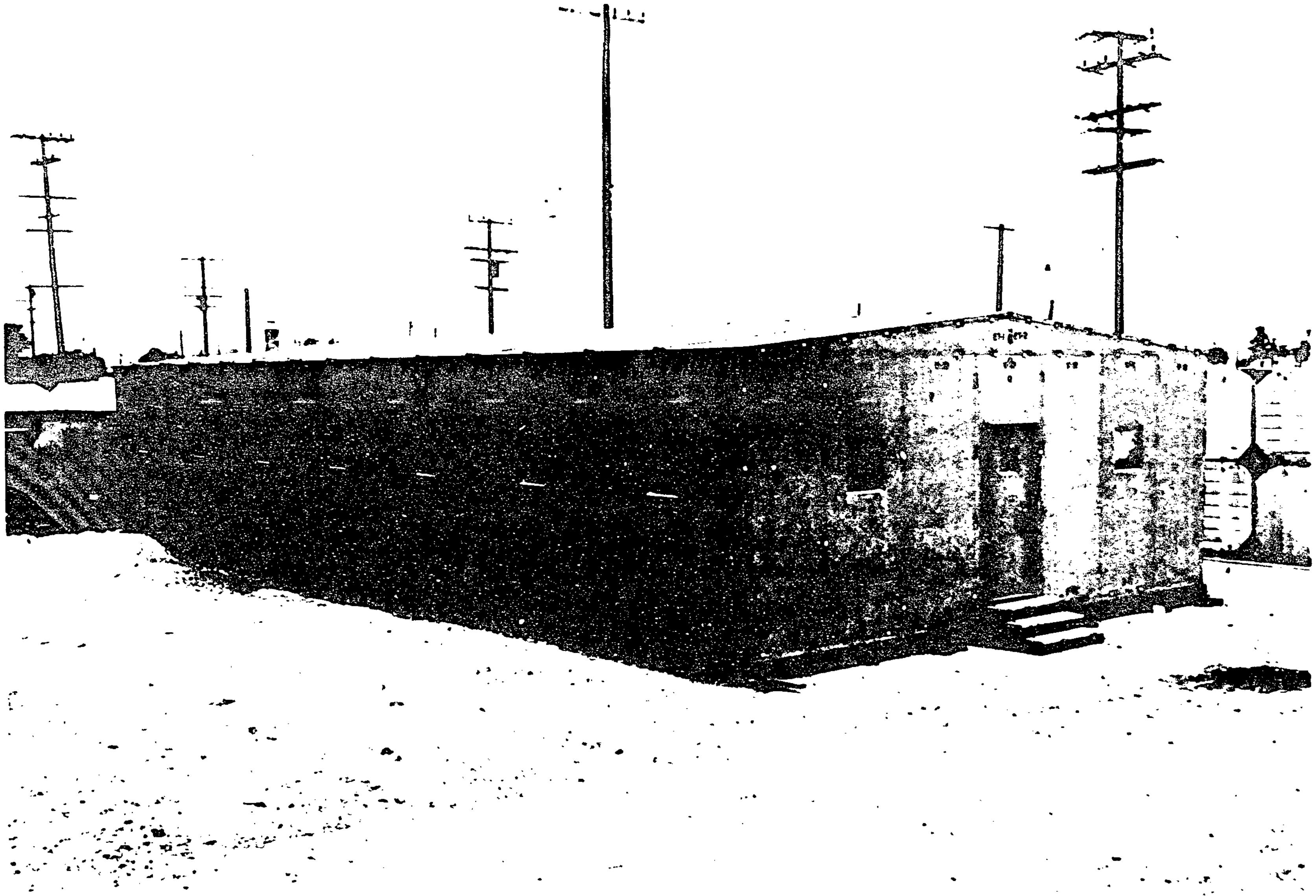


Figure 1. Modified T-5 Barracks.

## TEST FACILITY

The controlled climatic heating studies were conducted in the 60 x 60-foot environmental chamber at the Pacific Missile Range, Point Mugu, California. The building was elevated approximately 18 inches above the chamber floor on four timber sills placed under the sides of the building and under the longitudinal joints in the floor system. Air could circulate freely under the building through the open ends of the foundation and through nearly continuous 6-inch-high openings, the length of the sills.

Lack of clearance between the ends of the building and the walls of the cold chamber required relocation of the entrance door from the normal end location to a side location.

## CEILING MATERIALS

Two different types of ceiling materials were used during the various tests. One was 1/8-inch-thick perforated hardboard painted white. This material cost approximately $135.00, weighed 686 pounds, and had a volume of 17 cubic feet.

The other was 1-inch-thick semiridged acoustical fiberglas board faced with a washable decoratively embossed vinyl-plastic film. This material had a density of 0.17 pound per square foot, cost $251.00, weighed 266 pounds, and had a volume of 130 cubic feet.

Both ceiling materials are available in 2 x 4-foot sheets, which permits trimming to size with minimum waste. The ceiling pieces fit between the bottom chords of the steel roof trusses, with 1 x 1-inch aluminum T-splines used between panels to support adjoining edges. The splines weigh approximately 30 pounds, with an estimated cost of $90.00.

## PARTITION PANELS

For the tests of the two heating systems, two 8 x 12-foot rooms were created in the corner of the building farthest from the furnaces, to duplicate the partitioned quarters designed for the temporary polar camp barracks. In conformance with this design, the partition panels consisted of 1-1/2 x 1-1/2-inch wood framing with 1/4-inch plywood covering on both sides. Fiberglas insulation was used between the framing members for sound-deadening purposes.

## TEST SCHEDULE

The test schedule for the controlled climatic heating studies was designed to minimize the number of changes in the environmental chamber temperatures and to permit an overlap in operation of the heat sources. Both resulted in minimum delay for temperature stabilization. The tests were thus performed in the following sequence:

| Test | Ceiling Material | Chamber Temperature |
|---|---|---|
| Floor plenum system | perforated | 0 F |
| | perforated | -25 F |
| | perforated | -50 F |
| Heat-loss tests | perforated | -50 F |
| | no ceiling | -50 F |
| | fiberglas | -50 F |
| Overhead duct system | fiberglas | -50 F |
| | fiberglas | -25 F |
| | fiberglas | 0 F |
| Heat-loss tests | fiberglas | 0 F |
| | no ceiling | 0 F |

The building panels, foundation, and all major test components were moved into the test chamber, and the chamber was sealed. Erection of the building and installation of the floor plenum heating system were performed as the chamber temperature was lowered and stabilized at 0 F. Since the concrete floor of the test chamber constituted the largest heat sink, temperature measurements under the building were used to indicate the level of temperature stability in the chamber.

Upon completion of the tests of the floor plenum system, that system was removed and electric strip heaters were installed for the heat-loss tests at -50 F. Maximum utilization was made of test personnel by changing the ceiling materials and preparing for the tests of the overhead duct air-conditioning system during the day and obtaining heat-loss data at night. As the strip heaters and special

instrumentation for the heat-loss study would not interfere with the tests of the overhead duct system, they were kept in the building for completion of the heat-loss tests at 0 F. The entire test schedule including erection of the building, was completed in 26 days.

## PART II. HEAT-LOSS STUDY

Heat-loss and heat-transfer studies were conducted on the Modified T-5 Barracks to determine:

1. The overall heat-loss coefficient of the structural shell for T-5 type panelized buildings.

2. Comparative relationships between actual and theoretical heat losses.

3. The relative effectiveness of two different drop ceilings in reducing heat losses.

### TEST CONDITIONS

Heat-loss and -transmission tests were conducted on the building without ceiling or partitions at environmental chamber temperatures of -50 F and 0 F. Both ceiling materials were evaluated at -50 F, but the fiberglas ceiling only was tested at 0 F. Smoke-pipe, fuel-line, and other openings through the exterior walls and roof were closed with plugs of fiberglas insulation and taped to prevent unnatural infiltration. Temperature measurements were made at 24 locations within the building and four locations outside.

### HEAT SOURCE

Electric heating sources rather than combustion heaters were used during the heat-loss and heat-transmission studies in order to obtain greater accuracy and eliminate the problems associated with measurements of flue-gas volume, combustion efficiencies, and fuel-consumption rates. Twenty-six 1000-watt strip heaters were mounted on two steel racks (Figure 2), for a total nominal heating capacity of 89,000 Btuh. Both heating racks were controlled through magnetic relays by a single thermostat located at a quarterpoint along the centerline of the building. The heaters were placed near the center of the building facing in opposite directions, and two 2700-cfm electric fans were placed on the floor in diagonally opposite

corners to provide air circulation and as uniform a temperature distribution as possible. The heat output from the heaters was measured with two 220-volt, three-phase watt-hour meters, with one meter used on each heater bank.

## INSTRUMENTATION

Twenty-four thermocouples, read on two 16-channel automatic strip-recording potentiometers, were used for temperature measurements. The thermocouples were arranged in vertical strings and installed at the locations shown in Figure 3. The string of seven, at the center of the building, measured the floor surface temperature, air temperatures at 2, 30, and 60 inches above the floor, the ceiling surface temperature, the attic temperature 12 inches below the roof, and the roof undersurface temperature. The 3-thermocouple strings in the area facing the furnace and the area facing the rooms measured air temperatures 2, 30, and 60 inches above the floor. The two 5-thermocouple strings in the rooms measured the floor surface temperature, the air temperatures 2, 30, and 60 inches above the floor, and the ceiling surface temperature.

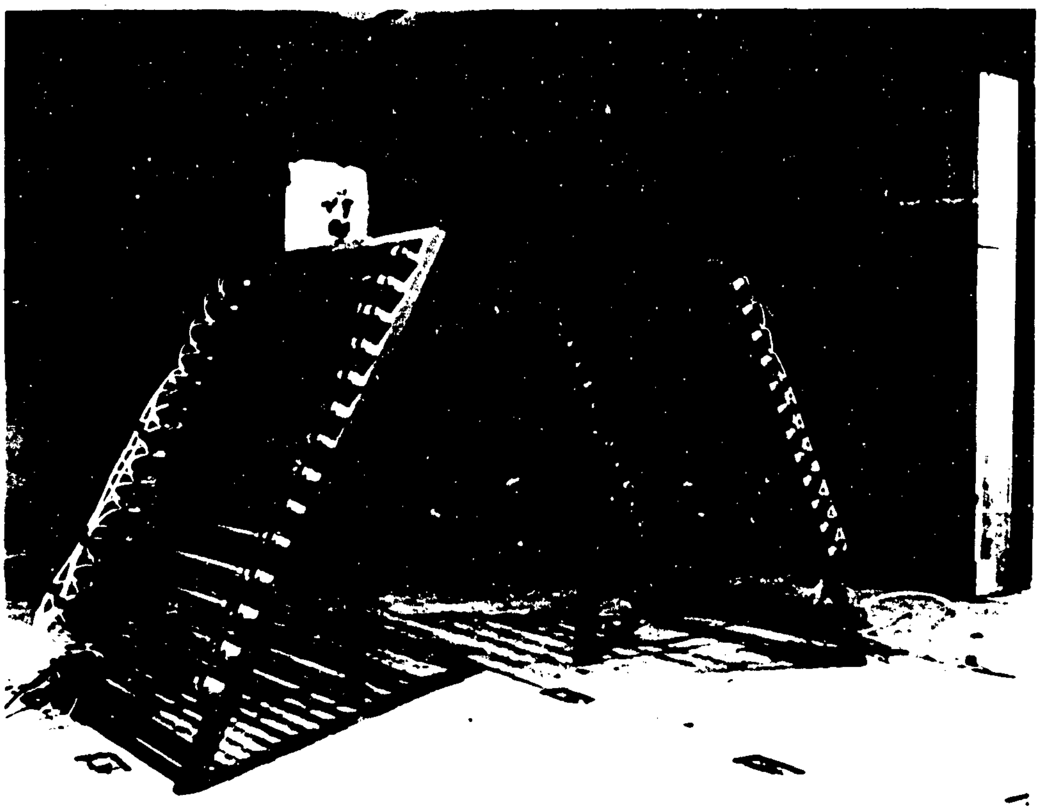
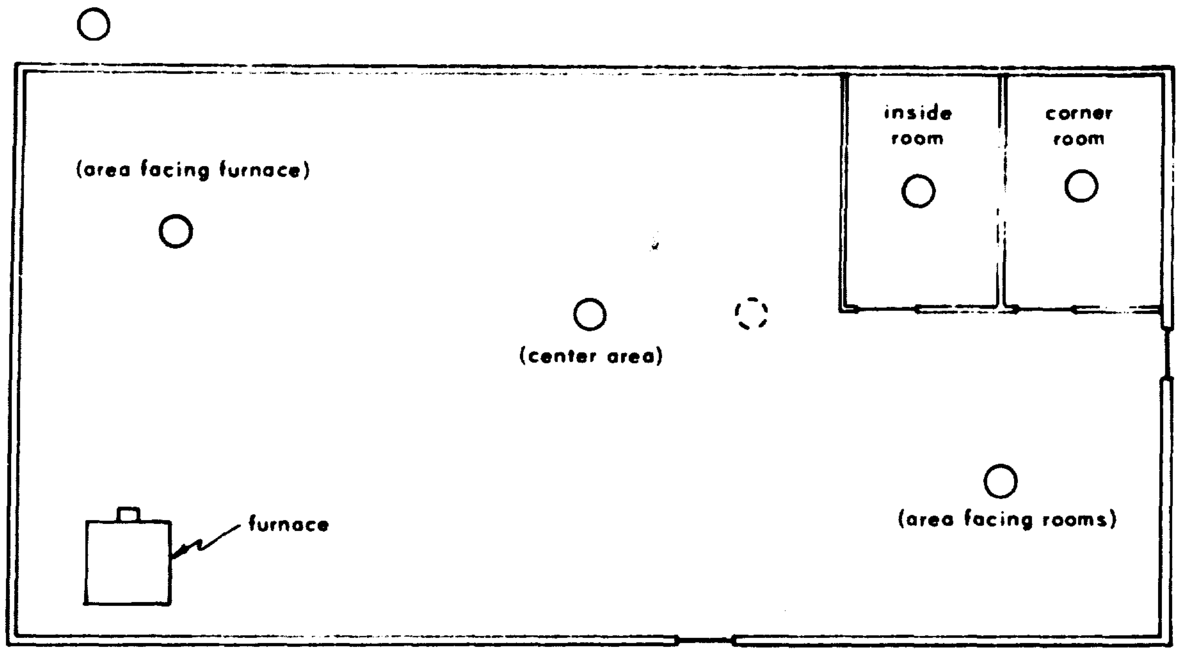
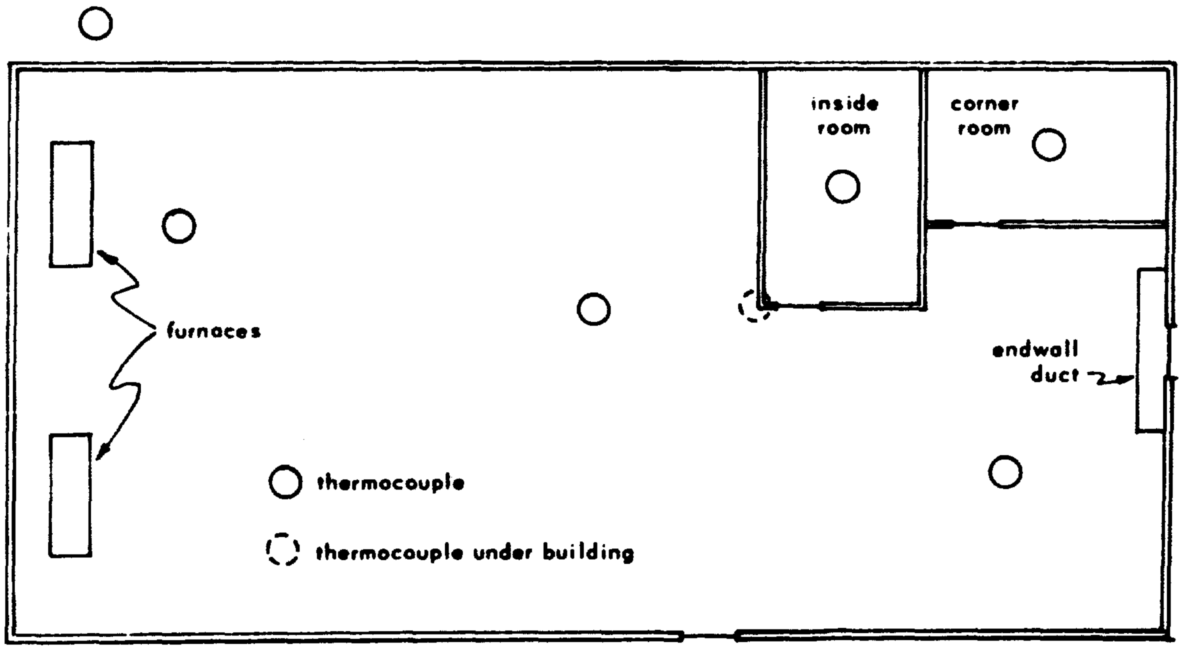


Figure 2. Electric heater racks.




Overhead Duct Tests




Floor Plenum Tests

Figure 3. Furnace and thermocouple locations and room arrangements.

Heat-transmission rates were measured on selected building panels with four Gier and Dunkle heat-flow meters. These meters contain a thermopile and an iron-constantan thermocouple laminated between 4-inch-square bakelite sheets to form a card approximately 1/16 inch thick. The cards were mounted with 1/4-inch wood screws through eight evenly spaced holes around the periphery in accordance with the manufacturer's recommendation. One of these meters was located on the wall, the floor, the underside of the roof, and one over a joint between two wall panels. The interface temperature from the heat meters was recorded on four channels of the recording potentiometer. The thermopile output was recorded through a selector switch on a single-channel continuous-recording potentiometer.

## PROCEDURE

Heat-loss studies began at a test chamber temperature of -50 F. A stabilization period in excess of 98 hours was allowed before data was taken for record. Each test period was 10 to 12 hours long and was conducted at night, with changes in ceiling materials made during the day. Heat loss from door openings was limited and generally occurred only once every 2 hours when watt-hour meter readings were taken. Readings of the Gier and Dunkle heat-flow meters were made near the conclusion of each test. Five-minute continuous recordings of the heat-flow meters were made both with and without the air-circulation fans operating.

## OVERALL HEAT LOSS

The overall heat loss values obtained from these tests, while not absolute, are a true representation of the losses which can be expected in actual building use. The two large fans used to circulate the air within the building undoubtedly increased the inside wall film conductance and thus increased the heat loss. However, this was offset by imperfect heat distribution and the inability to completely eliminate air stratification. Table I contains the average temperatures recorded at the various locations and shows the variation in heat distribution and the magnitude of stratification.

From the theoretical heat-loss calculation (Appendix A) it was estimated that, at -50 F, 73,700 Btuh would be lost through the wall, floor, and roof panels, and that 37,800 Btuh would be lost due to infiltration. The infiltration loss was based on one air change per hour, or 280 cfm. From Figure 4 it may be seen that the measured heat loss of 96,500 Btuh at -50 F is about 13.5 percent less than the calculated loss due to conduction and infiltration.

**Table 1. Average Temperatures (°F) Recorded During Heat-Loss Studies Showing Heat Distribution, Air Stratification, and Comparison of Temperatures With Different Ceiling Materials**

| Area | Test Number | | | | |
|---|---|---|---|---|---|
| | 13 Hardboard Ceiling (at -50 F)[1] | 14 No Ceiling (at -50 F) | 15 Fiberglas Ceiling (at -50 F) | 19 Fiberglas Ceiling (at -25 F) | 20 No Ceiling (at -25 F) |
| **Corner Room** | | | | | |
| Floor | 63 | 63 | 63 | 67 | 64 |
| Ankle | 72 | 69 | 71 | 70 | 69 |
| Waist | 74 | 71 | 73 | 71 | 71 |
| Shoulder | 74 | 71 | 73 | 72 | 71 |
| Ceiling | 74 | 72 | 73 | 72 | 71 |
| **Inside Room** | | | | | |
| Floor | 63 | 63 | 64 | 67 | 67 |
| Ankle | 73 | 71 | 74 | 71 | 70 |
| Waist | 76 | 71 | 74 | 72 | 72 |
| Shoulder | 76 | 71 | 74 | 72 | 72 |
| Ceiling | 75 | 71 | 73 | 71 | 72 |
| **Area Facing Rooms** | | | | | |
| Ankle | 74 | 71 | 71 | 71 | 71 |
| Waist | 75 | 72 | 73 | 72 | 72 |
| Shoulder | 75 | 72 | 72 | 72 | 72 |
| **Under Building** | | | | | |
| Under floor | -31 | -38 | -31 | 0 | 3 |
| 2 inches below | -41 | -46 | -40 | -4 | -2 |
| 12 inches below | -45 | -47 | -46 | -4 | [illegible] |
| **Center Area** | | | | | |
| Floor | 80 | 74 | 77 | 74 | 74 |
| Ankle | 80 | 74 | 78 | 76 | 75 |
| Waist | 81 | 74 | 79 | 76 | 75 |
| Shoulder | 82 | 77 | 82 | 79 | 77 |
| Ceiling | 74 | 83 | 85 | 83 | 84 |
| Attic | 70 | 86 | 54 | 60 | 84 |
| Roof | 64 | 80 | 48 | 57 | 81 |
| **Area Facing Furnace** | | | | | |
| Ankle | 74 | 72 | 74 | 72 | 73 |
| Waist | 76 | 73 | 75 | 73 | 73 |
| Shoulder | 76 | 73 | 75 | 74 | 74 |
| **Miscellaneous** | | | | | |
| Wall | 70 | 68 | 70 | 69 | 70 |
| Outside air 2 feet from wall | -50 | -50 | -48 | 9 | 1 |
| **Heat-Flow Meter Interface** | | | | | |
| Wall | 70 | 68 | 70 | 68 | 68 |
| Joint | 62 | 59 | 60 | 63 | 62 |
| Floor | — | 68 | 70 | 67 | 68 |
| Roof | 64 | 66 | 52 | 53 | 68 |

[1] Test chamber temperature

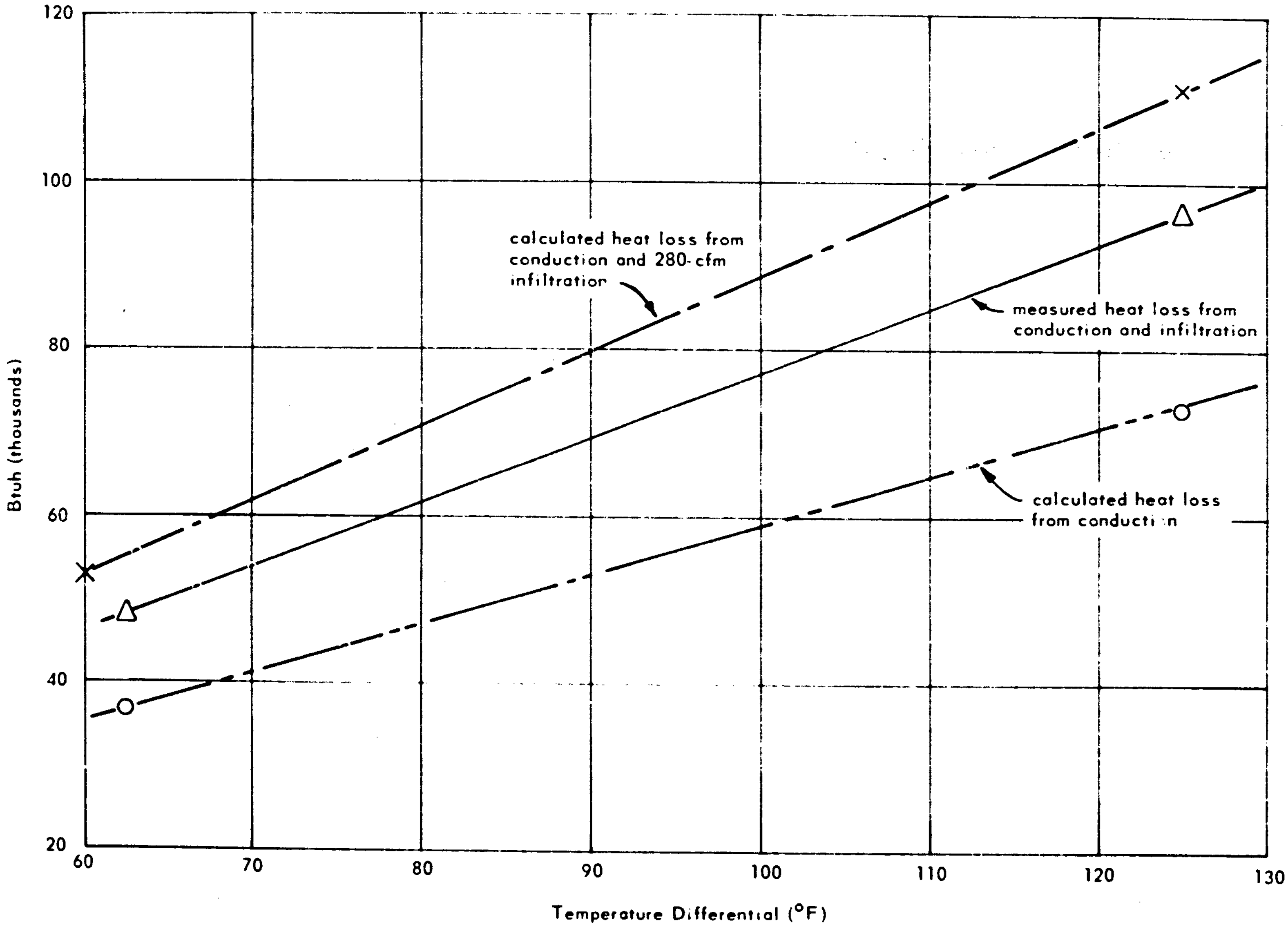



Figure 4. Comparison of calculated and measured heat losses from the Modified T-5 Barracks.

Based on the measured heat loss and the total square-footage of the walls, floor, and roof, a unit heat loss of 0.158 Btuh/sq ft/$^{o}$F is indicated at wind velocities of 2 to 3 miles per hour (those estimated in the test chamber). At wind velocities above 3 miles per hour, this unit heat loss will increase due to greater infiltration and the change in exterior film coefficients.

If the calculated heat loss of 73,700 Btuh through the building panels by conduction is precise, an infiltration rate of 170 cfm, or 0.6 air changes per hour, is indicated at the test conditions. Relating this air-leakage rate to half of the total linear feet of cracks (joints) in the building, a method occasionally used in determining infiltration losses, the resultant infiltration rate is 11.1 cubic feet per hour per foot. Only half of the total crack length is used since it is usually assumed that air enters on two sides of a rectangular building, and heated air leaves from the opposite sides.

The heat-flow meters used to measure the heat-transfer coefficient at selected panel locations gave results of only moderate consistency. Those measurements which were most representative were 10 to 12 percent below the theoretical heat-transfer coefficients of 0.093 Btuh/sq ft/$^{o}$F for the floor and roof and 0.092 Btuh/sq ft/$^{o}$F for the floor. The low coefficient obtained with these meters is attributed to poor contact between the meter and wall surface, which results in greater resistance to heat flow.

## CEILING EFFECTS

The use of the fiberglas ceiling in the Modified T-5 reduced the overall heat loss at -50 F from 96,500 Btuh to 71,000 Btuh, or 26 percent. The perforated hardboard ceiling, while not as effective, reduced the loss to 80,000 Btuh, or 17 percent, at the same temperature. Similar effectiveness of the two ceiling materials at other temperatures is shown graphically in Figure 5. Also shown is the approximate daily consumption of fuel oil at the full range of chamber temperatures. Use of the fiberglas ceiling resulted in a saving of 5.5 gallons per day at -50 F and 3.5 gallons per day at 0 F. The perforated hardboard ceiling, being a poorer insulator, resulted in a saving of 3.5 gallons per day at -50 F and 1.8 gallons per day at 0 F.

Figure 6 shows the mean monthly temperatures at McMurdo Sound during 1960 and the approximate fuel requirement for a Modified T-5 under these conditions. From this it is found that approximately 4400 gallons of fuel per year would be required to heat the building with no ceiling and 3200 gallons with the fiberglas ceiling, a saving of 1200 gallons or 8450 pounds of fuel. The estimated cost of

fuel oil at antarctic bases varies from $0.50 to $3.87 per gallon depending on the delivery point and the assumptions used in the calculation.[4] Assuming a fuel cost of $1.00 per gallon at the McMurdo Station, the cost of the fiberglas ceiling and supports can be amortized in less than 4 months. This approximation of possible fuel savings does not take into account the effects of wind velocity, solar radiation, or other influences on heat loss, since their effects are roughly equal regardless of ceiling.

The average air and surface temperatures under the roof also show the insulating effects of the different ceilings. At -50 F, the average temperature a foot below the roof at the center of the building was 86 F with no ceiling, 70 F with the perforated hardboard ceiling, and 54 F with the fiberglas ceiling. The corresponding roof undersurface temperature was 6 degrees lower in each case.

## FINDINGS

The heat-loss study of the 28 x 56-foot Modified T-5 Barracks showed that:

1. The overall heat loss is 0.158 Btuh/sq ft/°F at a wind velocity of 2 to 3 miles per hour.

2. The natural air-infiltration rate in the 4-foot-module panelized building is approximately 0.6 air changes per hour, or 11.1 cubic feet per hour per foot of joint based on half the total crack length.

3. A 1-inch-thick fiberglas board ceiling with a density of 0.17 pound per square foot will reduce the heat loss 26 percent and is 11 percent more effective than a ceiling of 1/8-inch perforated hardboard.

4. A 1-inch fiberglas ceiling will reduce the fuel consumption in the Modified T-5 from 4400 gallons a year to 3200 gallons at a location such as McMurdo Sound, Antarctica.

5. The roof undersurface temperature with the fiberglas ceiling averaged 48 F at -50 F outside temperature, which is 20 degrees above the dew-point temperature of room air at 75 F, 25 percent relative humidity.

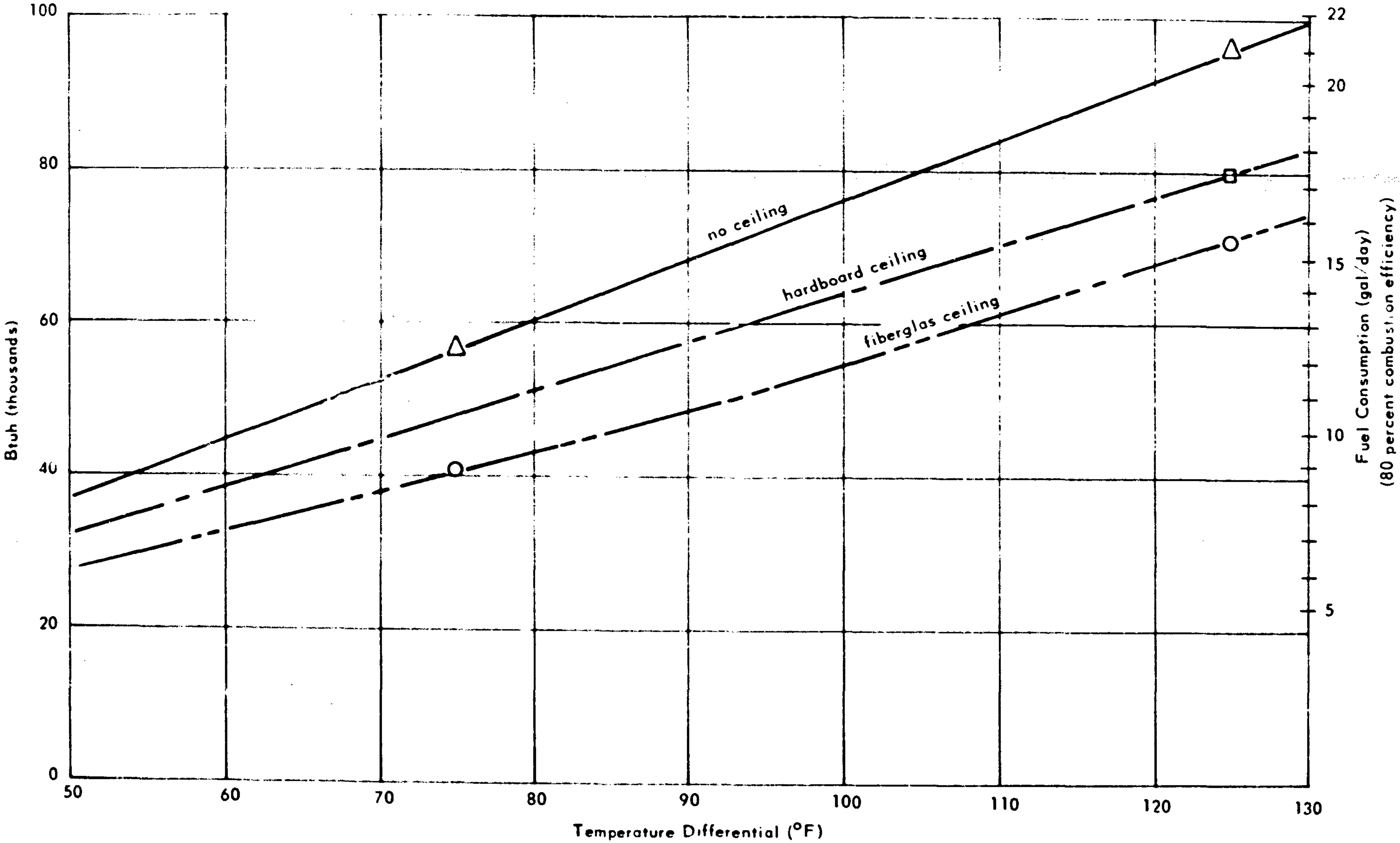



Figure 5. Effect of different ceiling materials in reducing heat loss and fuel-oil consumption.

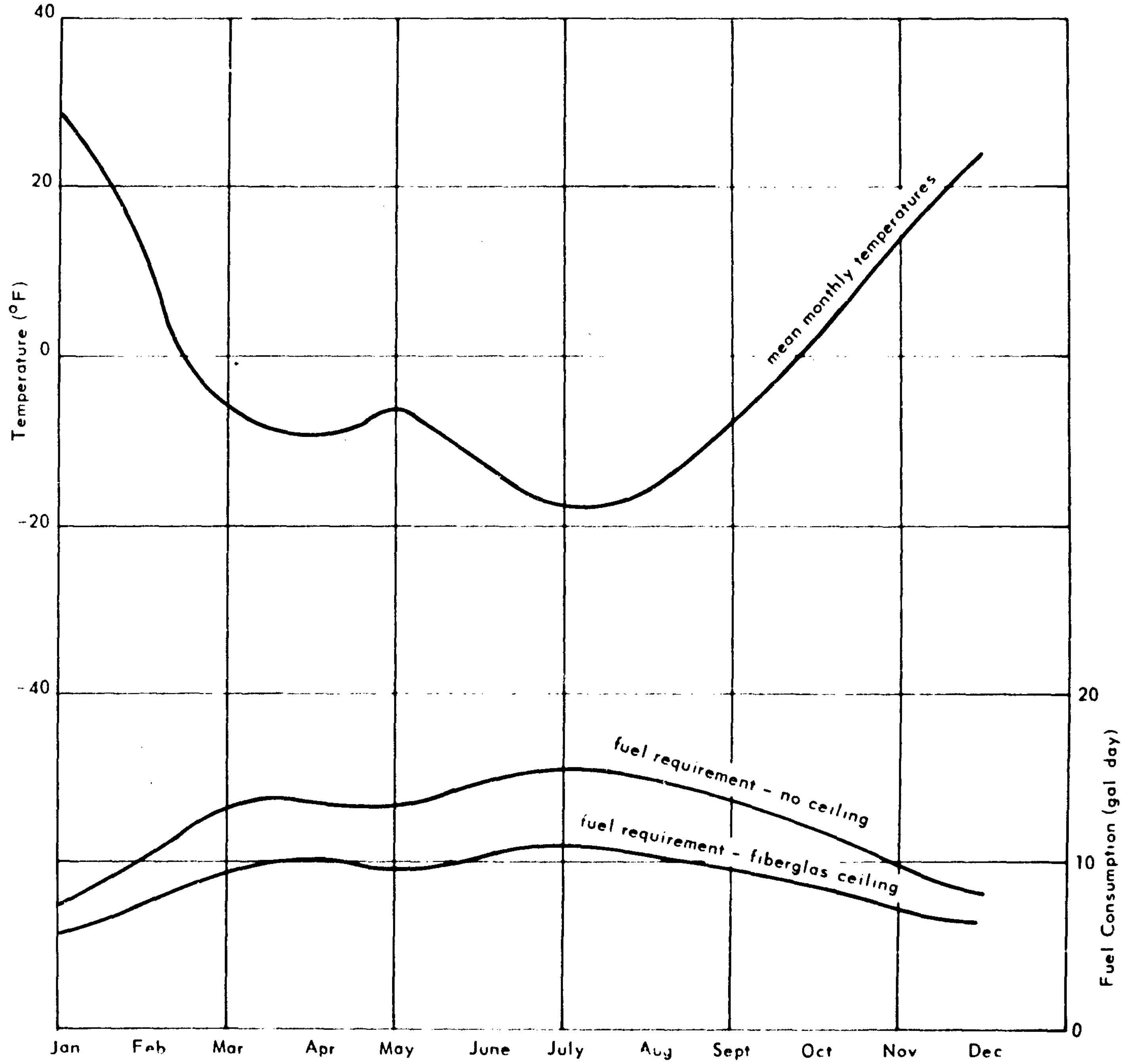



Figure 6. Approximate daily fuel-oil requirement for Modified T-5 based on mean monthly temperatures at McMurdo Sound in 1960. Effects of wind and solar radiation not included.

# PART III. FLOOR PLENUM HEATING SYSTEM

The principal objective of the USAERDL-designed floor plenum heating system was to improve occupant comfort through reduction of floor-to-ceiling temperature differences. The method employed was to pass the heated air through a false floor overlay before injecting it into the interior of the occupied building. By this method the occupied space is warmed both by radiation from the heated floor and by convection from the hot-air outlet at the end of the building. No provisions were made in this design for fresh-air ventilation, humidification, or other air conditioning.

## DESCRIPTION

The floor plenum system consists of two horizontal 95,000-Btuh oil-fired forced-air furnaces of the residential type. The furnaces are located at one end of the building, one on each side of the centerline (Figure 7). They discharge heated air through transition elbows into the 5-1/2-inch-deep false floor overlay which constitutes the floor plenum. The plenum is divided into two halves at the longitudinal centerline of the building, with one furnace feeding each half.

The plenum is made up of 5-inch-deep vanes on 12-inch centers, riveted at right angles to 1/2-inch-thick 4 x 8-foot plywood panels which serve as the plenum top and the building floor (Figure 8). Aluminum H-section splines are used between panels to lock them in place. The vanes are laid out so that the air passes the length of the plenum three times before being discharged into the room. The first pass of the air is through an 8-foot-wide section of the plenum along the outside wall. After making a 180-degree turn, it returns to the furnace end of the building in a 4-foot-wide section of the plenum, turns again, and makes the final pass in a 2-foot-wide section. The air then travels up the endwall in sheet-metal ducts and is discharged into the room through grills located over the endwall door (Figure 9). A 9-inch squirrel-cage blower in each vertical section of the endwall ducts assists the furnace blower in moving air through the plenum.

Controls on the plenum heating system were essentially those common to any oil-fired furnace. The only addition was a thermostatic switch located in the discharge duct from each furnace to control the operation of the duct-mounted blowers at the opposite end of the building. The usual wall-mounted thermostat was retained for each furnace.

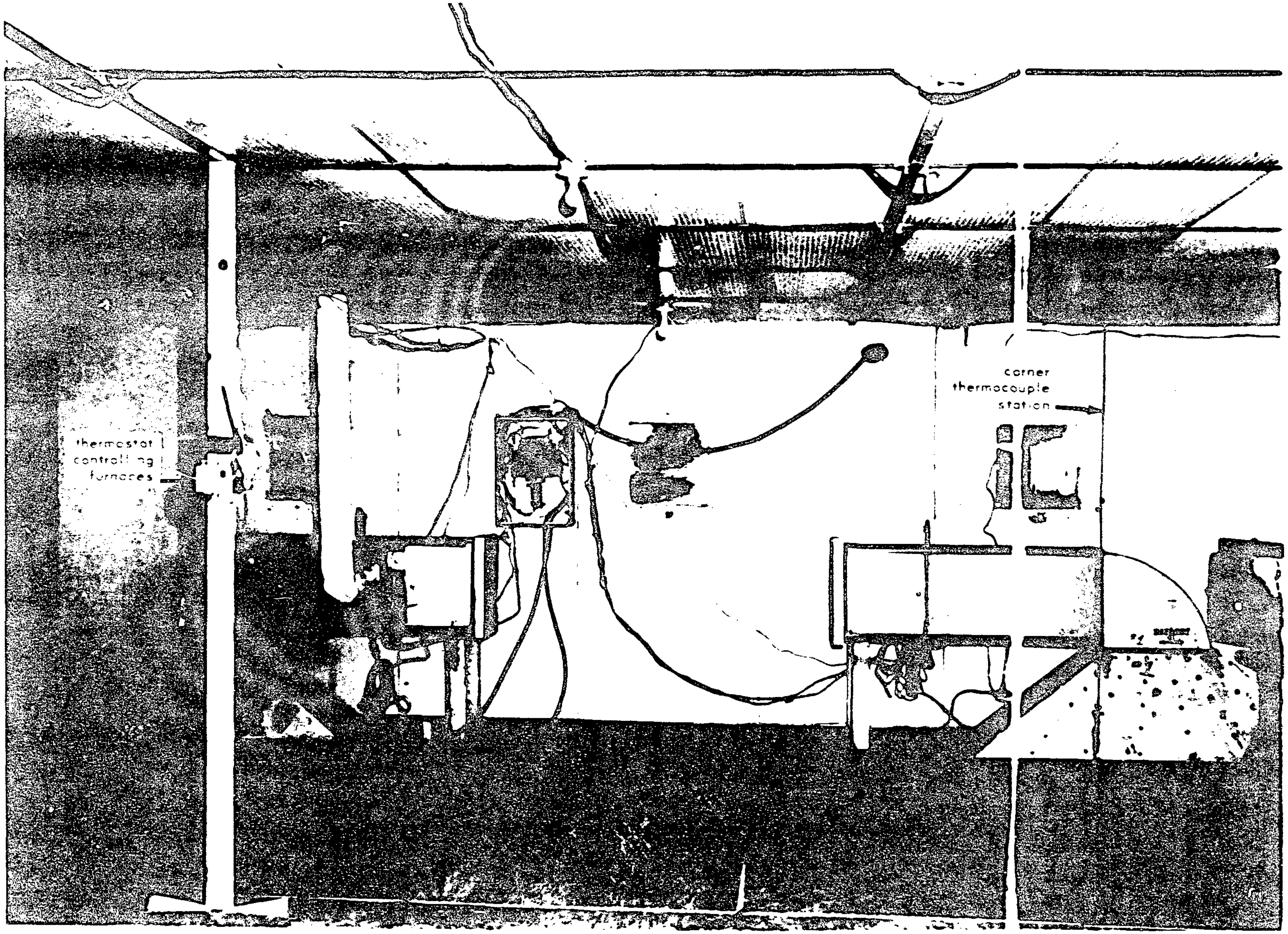
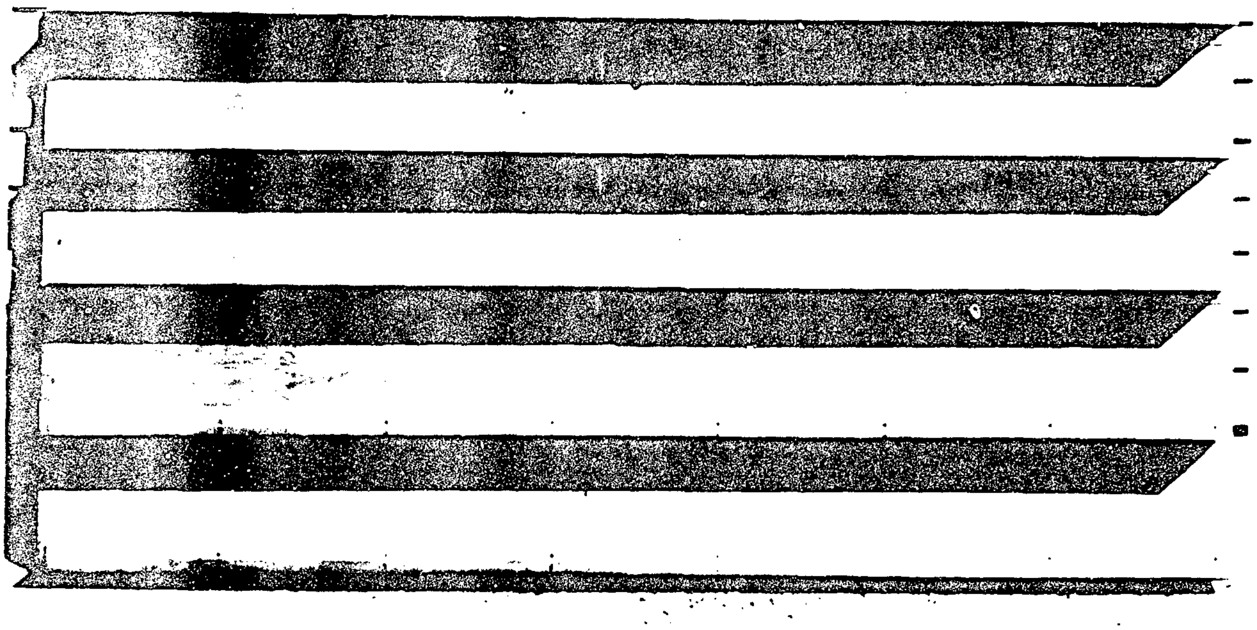
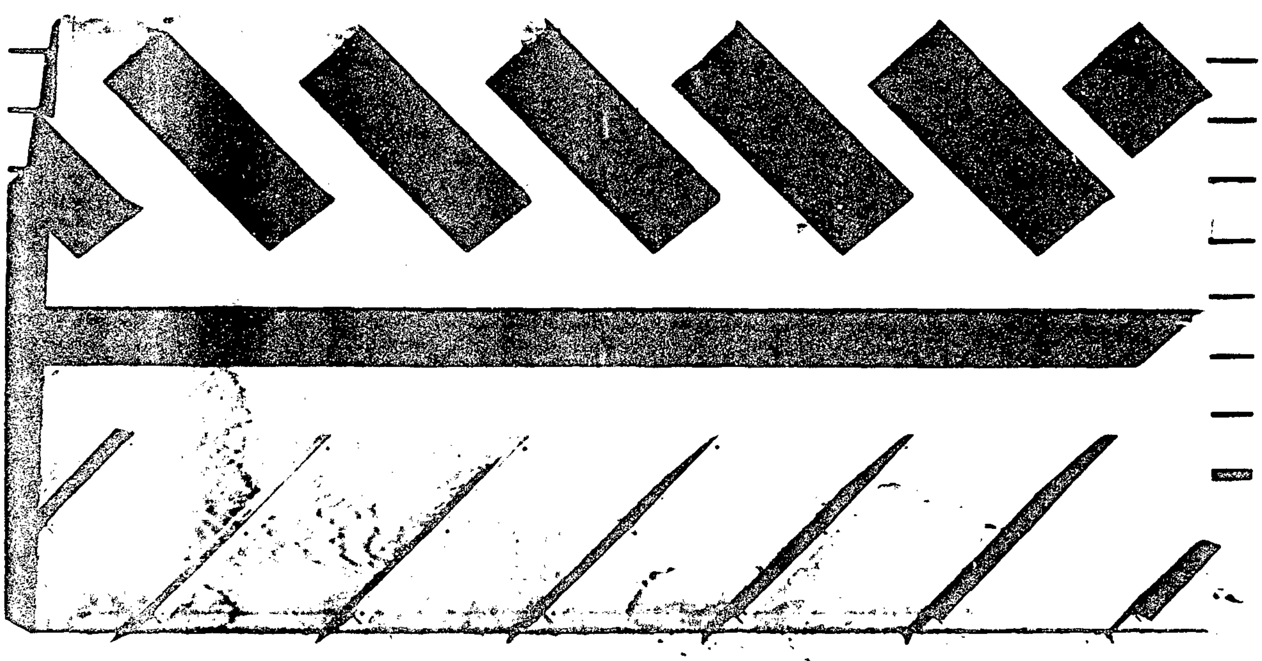



Figure 7. Floor plenum system test arrangement.



(a)



(b)

Figure 8. Plenum floor panels showing air-distribution vanes: (a) straight section, (b) corner section.

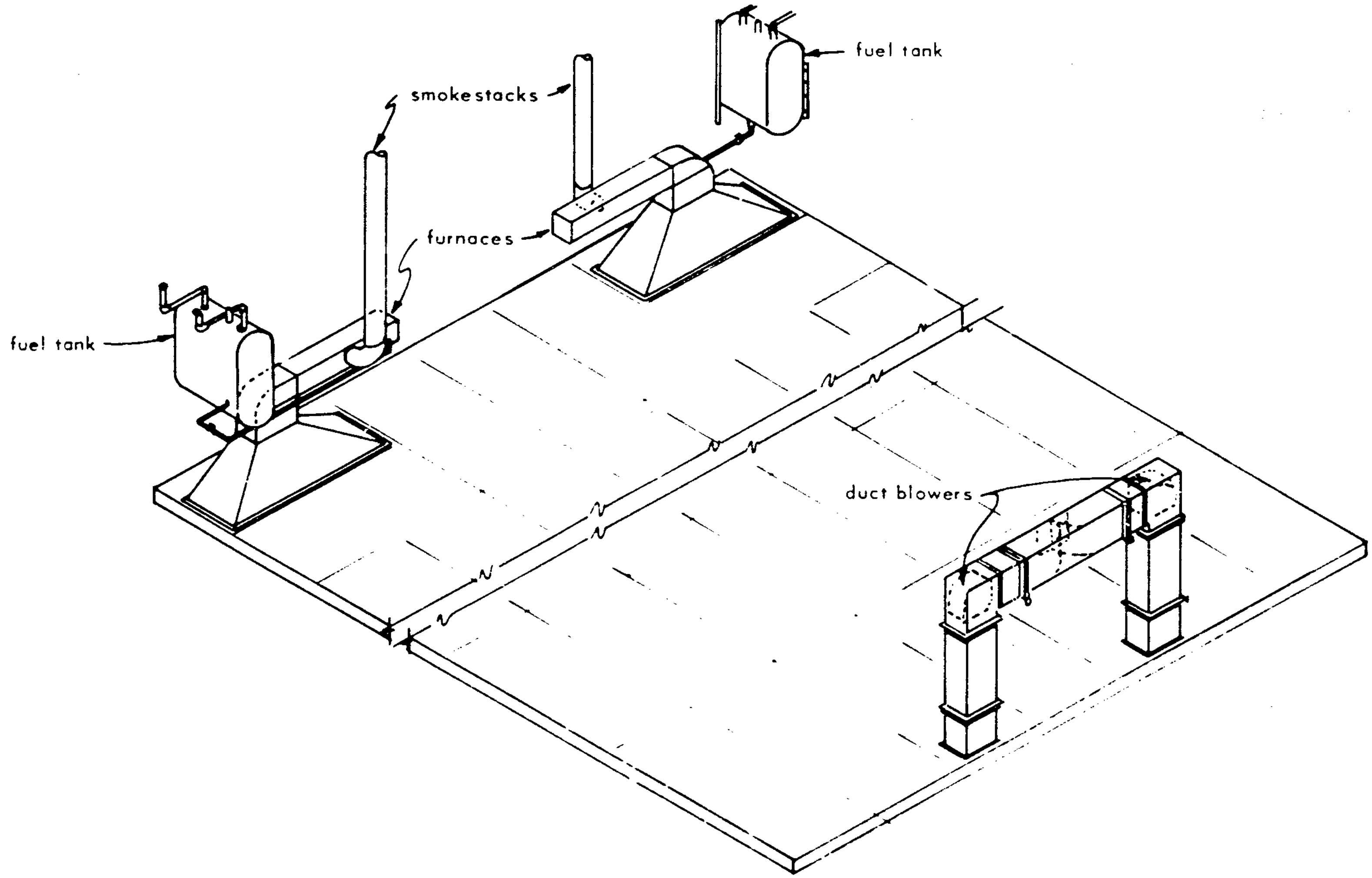



Figure 9. Plenum heating system isometric.

The system weighs approximately 4800 pounds and has a volume of 790 cubic feet. A breakdown of weight and volume for the major components is shown in Table II.

Table II. Weight and Cube of Floor Plenum Heating System

| | Net Weight (lb) | Net Cube (cu ft) |
|---|---|---|
| Furnaces, 2 ea. | 780 | 60 |
| Transition Ducts, 2 ea. | 240 | 170 |
| Plenum Floor | 3,300 | 450 nested |
| Floor Splines | 70 | 10 |
| Endwall Duct | 240 | 60 |
| Smoke Pipe, 2 ea. | 80 | 10 |
| Roof Jack, 2 ea. | 90 | 30 |
| | 4,800 | 790 |

## TEST CONDITIONS

Installation of the floor plenum system was carried out as designed. The only deviation was the use of a single 275-gallon fuel tank located outside the building, rather than the two 160-gallon tanks supplied with the system for interior mounting. This change simplified fueling and reduced the fire hazard within the building.

Flue gases from the furnaces were carried from the test chamber through two 7-inch-diameter ducts. The only ports in the chamber walls through which these ducts could pass required an average horizontal run of 30 feet. To assure an adequate draft, the flue ducts terminated in a power-exhaust duct from a lavatory adjacent to the chamber. The suction fan on this exhaust duct resulted in an abnormally large volume of air entering the furnace flue-gas ducts at the draft regulators (approximately 300 cfm). This was not detrimental to the tests as it approximated the volume of air which might be expected to infiltrate the building under in-service wind conditions of 30 to 40 miles per hour. Also, this exhausting of air diminished the possibility of carbon monoxide accumulation in the building or chamber during the three-week test program.

When erecting the two 8 x 12-foot rooms it was planned that the 8-foot room dimensions would be on the building sidewall. However, this could not be accomplished during the floor plenum heating tests since the endwall heat duct interfered with installation of the panels. As a result, the corner room only was installed with its 12-foot dimension on the sidewall (Figure 3).

Before beginning the floor plenum tests, a 6 x 12-inch floor register was cut into the plenum in each room near the sidewall. Later the opening in the corner room was sealed, and a new opening was cut near the door of the room 7 feet from both the end and side of the building. These registers were recommended by USAERDL,[1] if needed, to admit heat to the rooms by convection as well as radiation. A 6 x 12-inch cold-air return register was also provided near the bottom of the door in each room.

The perforated ceiling was used in the unpartitioned part of the building for all of the floor plenum tests. Four tests were conducted at each test chamber temperature (0 F, -25 F, and -50 F); two with perforated hardboard ceiling and two with fiberglas ceiling over the rooms. For each ceiling material, one test was made with the floor registers and return-air grills open and the other with those openings closed. The tests were carried out on a continuous schedule, with an average of two tests per day and 6 hours or more of stable operation during each test. After the first test the two furnaces were connected to operate from a single thermostat located near the center of the building, because the two furnaces could not be made to operate together when controlled by individual thermostats.

## INSTRUMENTATION

The thermocouple temperature-measurement network was the same as that used during the heat-loss study. In addition, an Alnor Velometer was used to measure air velocity.

## MECHANICAL PERFORMANCE

Some difficulty was experienced in putting the two furnaces in operation at 0 F. The greatest of these occurred with the 1/3-horsepower electric motors driving the furnace blowers. The drive belts were not excessively stiff, and the motors turned freely with the belts removed. However, when connected to the blowers, the motors overheated and their thermal overload cutouts shut them off. One furnace was put into operation by replacing the 1/3-horsepower motor with a 1/2-horsepower motor, and no further difficulty was encountered. The second furnace blower could not be put into operation until the building temperature reached about 40 F.

It appeared that the motors were of marginal capacity and did not have sufficient power to handle the cold air of increased density. Horsepower requirements as specified by blower manufacturers are based on a standard air temperature of 70 F. Cooling to 0 F increases the air density and, consequently, the fan horsepower requirement by 17 percent.

During the first test with the floor registers in the rooms open, it was found that very little air was emitted from the register in the corner room because of the underlying baffle arrangement. When the new register opening was cut in the floor near the door, a larger volume of air was obtained and attention was drawn to some interesting facts about the operation of the system.

It was found that when the furnaces and duct blowers were operating, air was emitted from the register at about 200 cfm; but when the thermostatically controlled furnace blowers went off, air was drawn from the room into the plenum at about 100 cfm. This could be expected with the arrangement of the blowers in the system. Further observation disclosed that at the initial duct thermostat setting, the duct blowers operated continuously and did not cycle. Since both the duct and furnace thermostats close on temperature rise, it was apparent that the temperature at the duct thermostat location never dropped below its turnoff setting. It was also found that while the furnace blower cycled, it went on and off only once during each period of oil burner operation. (In a single-blower heating system, the blower normally cycles three or four times during each burner cycle.) An attempt was made to produce cycling in the duct blower by changing its thermostat setting. This was done in minimum increments until a setting was reached which caused the blowers to turn off. At this point, however, the duct blowers failed to come on during any of the next several burner cycles because the setting was higher than that for the furnace blower, and the temperature did not reach that point. Under this condition, the furnace blowers began their usual operation of three to four cycles per burner cycle.

The only apparent method to produce cycling in the duct blowers would be to parallel them with the furnace blower or to replace the duct thermostat with one having a narrower on-and-off span. This was not done, and the thermostats were returned to their original setting since it appeared desirable to have continuous air movement through the floor plenum. The only disadvantage to continuous operation of the duct blower was the reversed flow of air through the floor registers.

## HEATING PERFORMANCE

When conducting the tests, it was found that a temperature of about 74 F, 60 inches above the floor was comfortable for the personnel working in the building. The thermostat controlling both furnaces was set at this temperature and was not

changed during the floor plenum system tests. The 13 tests conducted with the floor plenum system and the conditions for each are listed in Table III. Test numbers are shown for reference in presenting the results.

A summary of the temperature measurements taken during each of the 13 tests is contained in Appendix B. This summary shows the lateral variation in heat distribution and the vertical effects of stratification. Each temperature shown is the average of 13 or 18 individual readings taken during 2 hours of each stable test period. The individual temperatures making up these averages were very consistent, with a variation of only a few degrees between the highest and lowest readings.

A comparison of Tests 1, 7, and 9, which were conducted at 0, -25, and -50 F respectively with the perforated hardboard ceiling over the rooms and the floor registers closed, is shown in Table IV. It is apparent that heat radiated through the floor was not sufficient to keep the corner room comfortable at any of the outside (test chamber) temperatures. For example, the average temperature at shoulder height in the corner room was 67 F at 0 F, 61 F at -25 F, and 63 F at -50 F; while the temperature in the inside room was 75 F, 74 F, and 75 F. Across the building in the unpartitioned space, the temperature at the same height was 78 F, 74 F, and 74 F respectively. The floor surface temperatures were the highest temperatures recorded in the rooms. Air stratification was minimal, with only a 3- to 4-degree variation between ankle and head heights.

Table V shows comparative figures for the two rooms with the fiberglas ceiling installed and the floor registers closed. The change in ceiling over the rooms resulted in a nearly uniform 2-degree increase in temperature, while the temperatures on the opposite side of the building where the ceiling was not changed remained essentially constant. The corner room temperatures of 60 to 63 degrees at the ankles and 63 to 65 degrees at the shoulders were still not at a comfortable level.

Table VI shows the average temperatures obtained in the two rooms with the perforated hardboard ceiling and with the fiberglas ceiling. The floor and return-air registers were open during these tests. Again, it may be seen that the fiberglas ceiling resulted in 2 to 3 higher degrees of temperature, while temperatures in the area opposite the rooms were essentially constant.

From Table VI it would appear that the plenum registers would maintain the corner room at a comfortable level. However, examination of the individual measurements which make up those averages (Table VII) shows an uncomfortably wide temperature variation. This variation is rhythmic in some instances, with the frequency corresponding to operating cycles of the furnaces.

Table III. Schedule of Floor Plenum Heating System Tests

| Test No. | Chamber Temperature | Floor Register and Return Air | Room Ceiling Material | Remaining Ceiling Material |
|---|---|---|---|---|
| 1 | 0 F | Closed | Hardboard | Hardboard |
| 2 | 0 F | Open | Hardboard | Hardboard |
| 3 | 0 F | Closed | Fiberglas | Hardboard |
| 4 | 0 F | Open | Fiberglas | Hardboard |
| 5 | -25 F | Closed | Fiberglas | Hardboard |
| 6 | -25 F | Open | Fiberglas | Hardboard |
| 7 | -25 F | Closed | Hardboard | Hardboard |
| 8 | -25 F | Open | Hardboard | Hardboard |
| 9 | -50 F | Closed | Hardboard | Hardboard |
| 10 | -50 F | Open | Hardboard | Hardboard |
| 11 | -50 F | Closed | Fiberglas | Hardboard |
| 12 | -50 F | Open | Fiberglas | Hardboard |
| 12A 1/ | -50 F | Closed | Fiberglas | Hardboard |

1/ Duct blowers off

Table IV. Floor Plenum Tests: Comparison of Average Inside Temperatures at Different Outside Temperatures (°F) — Hardboard Ceiling, Registers Closed

| Test No. | Test Chamber Temp. | Corner Room | | | | | Inside Room | | | | | Area Facing Rooms | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Floor | Ankle | Waist | Shoulder | Ceiling | Floor | Ankle | Waist | Shoulder | Ceiling | Ankle | Waist | Shoulder |
| 1 | 0 | 67 | 65 | 67 | 67 | 66 | 81 | 76 | 75 | 75 | 74 | 78 | 78 | 78 |
| 7 | -25 | 63 | 58 | 61 | 61 | 59 | 82 | 75 | 74 | 74 | 69 | 75 | 75 | 74 |
| 9 | -50 | 67 | 60 | 62 | 63 | 60 | 84 | 76 | 75 | 75 | 70 | 75 | 74 | 74 |

Table V. Floor Plenum Tests: Comparison of Average Inside Temperatures at Different Outside Temperatures (°F) — Fiberglas Ceiling, Registers Closed

| Test No. | Test Chamber Temp. | Corner Room | | | | | Inside Room | | | | | Area Facing Rooms | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Floor | Ankle | Waist | Shoulder | Ceiling | Floor | Ankle | Waist | Shoulder | Ceiling | Ankle | Shoulder | Ceiling |
| 3 | 0 | 65 | 63 | 65 | 65 | 65 | 83 | 78 | 77 | 77 | 76 | 73 | 74 | 75 |
| 5 | -25 | 63 | 60 | 63 | 63 | 61 | 85 | 79 | 77 | 77 | 77 | 74 | 74 | 74 |
| 11 | -50 | 68 | 62 | 64 | 64 | 62 | 85 | 78 | 77 | 77 | 75 | 75 | 74 | 74 |

Table VI. Floor Plenum Tests: Comparison of Room Temperatures (°F) When Floor Registers and Cold-Air Return are Open

| Test No. | Test Chamber Temp. | Corner Room | | | | | Inside Room | | | | | Area Facing Rooms | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Floor | Ankle | Waist | Shoulder | Ceiling | Floor | Ankle | Waist | Shoulder | Ceiling | Ankle | Waist | Shoulder |
| | | Perforated Hardboard Ceiling Throughout | | | | | | | | | | | | |
| 2 | 0 | 75 | 72 | 74 | 74 | 74 | 88 | 82 | 81 | 81 | 81 | 75 | 76 | 76 |
| 8 | -25 | 76 | 72 | 77 | 78 | 75 | 84 | 78 | 76 | 76 | 73 | 74 | 74 | 74 |
| 10 | -50 | 78 | 74 | 80 | 80 | 78 | 84 | 78 | 76 | 76 | 72 | 75 | 74 | 74 |
| | | Fiberglas Ceiling Over Rooms — Remainder Hardboard | | | | | | | | | | | | |
| 4 | 0 | 76 | 74 | 77 | 77 | 75 | 84 | 80 | 78 | 78 | 78 | 73 | 74 | 74 |
| 6 | -25 | 76 | 74 | 79 | 79 | 78 | 86 | 81 | 79 | 79 | 79 | 73 | 74 | 73 |
| 12 | -50 | 81 | 77 | 81 | 82 | 79 | 86 | 80 | 78 | 78 | 76 | 74 | 74 | 74 |
| 12A[1] | -50 | 94 | 91 | 92 | 92 | 89 | 88 | 85 | 84 | 84 | 83 | 75 | 76 | 76 |

1/ Duct blowers off

Table VII. Floor Plenum Test 8: Temperature Readings at 8-Minute Intervals (°F) — Chamber Temperature -25 F, Perforated Hardboard Ceiling, Registers Open

| Time | Corner Room | | | | | Inside Room | | | | | Area Facing Rooms | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Floor | Ankle | Waist | Shoulder | Ceiling | Floor | Ankle | Waist | Shoulder | Ceiling | Ankle | Waist | Shoulder |
| 1200 | 76 | 72 | 79 | 79 | 77 | 84 | 78 | 77 | 77 | 74 | 76 | 76 | 75 |
| 1208 | 78 | 72 | 75 | 75 | 72 | 84 | 76 | 76 | 75 | 72 | 70 | 72 | 72 |
| 1216 | 73 | 70 | 76 | 76 | 75 | 83 | 78 | 77 | 77 | 74 | 77 | 75 | 75 |
| 1224 | 78 | 74 | 81 | 81 | 78 | 85 | 74 | 78 | 77 | 73 | 76 | 76 | 76 |
| 1232 | 77 | 71 | 74 | 74 | 71 | 84 | 76 | 76 | 75 | 72 | 73 | 73 | 73 |
| 1240 | 70 | 67 | 71 | 72 | 71 | 82 | 77 | 76 | 75 | 73 | 74 | 74 | 74 |
| 1248 | 75 | 73 | 79 | 79 | 77 | 84 | 79 | 77 | 77 | 74 | 78 | 76 | 76 |
| 1256 | 30 | 75 | 79 | 79 | 76 | 85 | 77 | 76 | 76 | 73 | 75 | 75 | 74 |
| 1304 | 74 | 70 | 73 | 72 | 70 | 83 | 76 | 75 | 75 | 72 | 73 | 72 | 72 |
| 1312 | 73 | 71 | 77 | 7[illegible] | 75 | 82 | 77 | 77 | 76 | 74 | 73 | 73 | 73 |
| 1320 | 79 | 75 | 81 | 82 | 79 | 84 | 79 | 77 | 77 | 74 | 76 | 75 | 75 |
| 1328 | 81 | 74 | 78 | 78 | 75 | 85 | 77 | 76 | 76 | 73 | 74 | 74 | 74 |
| 1336 | 71 | 70 | 73 | 73 | 71 | 83 | 76 | 75 | 75 | 73 | 75 | 73 | 73 |
| 1344 | 75 | 73 | 78 | 79 | 77 | 83 | 78 | 77 | 77 | 74 | 77 | 75 | 75 |
| 1352 | 80 | 76 | 82 | 83 | 80 | 85 | 78 | 77 | 77 | 74 | 73 | 74 | 74 |
| 1400 | 79 | 72 | 75 | 75 | 72 | 83 | 76 | 75 | 75 | 73 | 70 | 71 | 71 |
| 1408 | 76 | 73 | 79 | 79 | 77 | 84 | 80 | 77 | 77 | 74 | 76 | 75 | 75 |
| 1416 | 81 | 76 | 82 | 83 | 81 | 84 | 79 | 78 | 78 | 75 | 78 | 76 | 76 |
| Average | 76 | 72 | 77 | 78 | 75 | 84 | 78 | 76 | 76 | 73 | 74 | 74 | 74 |

The last test of the plenum system, Test 12A, was conducted with the duct blowers turned off to determine the effect on room temperatures. The temperatures in both rooms rose above the comfortable level, while the remainder of the building was virtually unaffected (Table VIII).

Floor surface temperatures in the unpartitioned portion of the building averaged 79 F at 0 F outside temperature, 77 F at -25 F, and 75 F at -50 F. The unqualified opinion of personnel conducting the tests considered these temperatures to be uncomfortably warm to the feet. The ASHRAE Guide[5] states that "floor panel surface temperatures in excess of about 85 F are not recommended because of the probability of discomfort to the feet." This design criterion refers to radiant floor panel heating systems in fairly temperate climates where lightweight footwear is common. Since insulated footwear is usual in the polar regions, it is considered that 70 F represents a more realistic maximum temperature for floors in these areas.

## FINDINGS

The controlled climatic heating study of the floor plenum system showed that:

1. The partitioned rooms with fiberglas ceiling were a nearly uniform 2 degrees warmer than the same rooms with hardboard ceiling at all test temperatures.

2. Air stratification was minimal and varied only 3 to 4 degrees between floor and ceiling.

3. Radiation through the floor was not sufficient to keep the corner room with two outside walls at a comfortable temperature at any of the outside test temperatures.

4. Floor registers in the plenum floor were not effective in raising the temperature in the underheated corner room.

5. Radiation through the floor of the interior room with one outside wall produced overheating even though the unpartitioned space was at a comfortable temperature.

6. Floor surface temperatures in the unpartitioned portion of the building varied from 75 F to 79 F.

Table VIII. Floor Plenum Tests: Comparative Temperatures (°F) With and Without Duct Blowers Operating

| Area | Test Number | |
|---|---|---|
| | 12<br>Duct Blowers On<br>(at -50 F)1/ | 12A<br>Duct Blowers Off<br>(at -50 F) |
| **Corner Room** | | |
| Floor | 81 | 94 |
| Ankle | 77 | 91 |
| Waist | 81 | 92 |
| Shoulder | 82 | 92 |
| Ceiling | 79 | 89 |
| **Inside Room** | | |
| Floor | 86 | 88 |
| Ankle | 80 | 85 |
| Waist | 78 | 84 |
| Shoulder | 78 | 84 |
| Ceiling | 76 | 83 |
| **Area Facing Rooms** | | |
| Ankle | 74 | 75 |
| Waist | 74 | 76 |
| Shoulder | 74 | 76 |
| **Under Building** | | |
| Floor | -31 | -34 |
| 4 inches below | -42 | -44 |
| 10 inches below | -44 | -45 |
| **Center Area** | | |
| Floor | 73 | 73 |
| Ankle | 74 | 73 |
| Waist | 74 | 75 |
| Shoulder | 75 | 77 |
| Ceiling | 70 | 73 |
| Attic 12 inches under roof | 62 | 69 |
| Roof | 54 | 59 |
| **Area Facing Furnace** | | |
| Ankle | 73 | 74 |
| Waist | 74 | 75 |
| Shoulder | 75 | 76 |
| **Miscellaneous** | | |
| Wall | 64 | 67 |
| Outside air 2 feet from wall | -47 | -44 |
| **Heat-Flow Meter Interface** | | |
| Wall | 64 | 66 |
| Joint | 56 | 56 |
| Floor | 2/ | 2/ |
| Roof | 48 | 52 |

1/ Test chamber temperature
2/ Meter not operating

## PART IV. OVERHEAD DUCT AIR-CONDITIONING SYSTEM

The overhead duct air-conditioning system was designed for the packaged temporary polar camp being developed by the Laboratory, to provide heating, fresh-air ventilation, and humidification of the habited space. In this design, two 52-foot-long buildings of the Modified T-5 type are connected by a 16-foot-long utility core.[2] Since only one 56-foot Modified T-5 was available for test, the first 8 feet of one side was used for the utilities and only half of the duplex system was tested. The furnace humidification equipment, ventilation air inlets, and the other components were scaled down accordingly.

Commercial components were chosen insofar as possible with consideration given to ease and speed of assembly by inexperienced personnel.

### DESCRIPTION

The furnace, located in the southwest corner of the building, was a 140,000-Btuh upright oil-fired model with a 2000-cfm forced-circulation blower located below the heat exchanger. Warm air discharged at the top of the furnace was carried to the centerline of the building through rectangular sheet-metal ductwork, then down the centerline below the trusses through 10 x 30-inch fiberglas board ducts (Figures 10 and 11). Four- by fourteen-inch dampered registers cut into both sides of the supply duct every 8 feet discharged the air across and down toward the outside walls. The air was returned to the furnace through two 12-inch-diameter duct inlets in the ceiling a few feet from the furnace. Five-hundred cfm of ventilation air (2.1 air changes per hour in the habited space) was drawn into the building through an opening in the sidewall and mixed with the return air before it entered the furnace.

A humidifier was mounted in the straight section of hot-air duct between the furnace and the transition to the fiberglas duct. This unit has a capacity of 12 pounds of water per hour, which is atomized mechanically by dripping on a rapidly spinning disc.

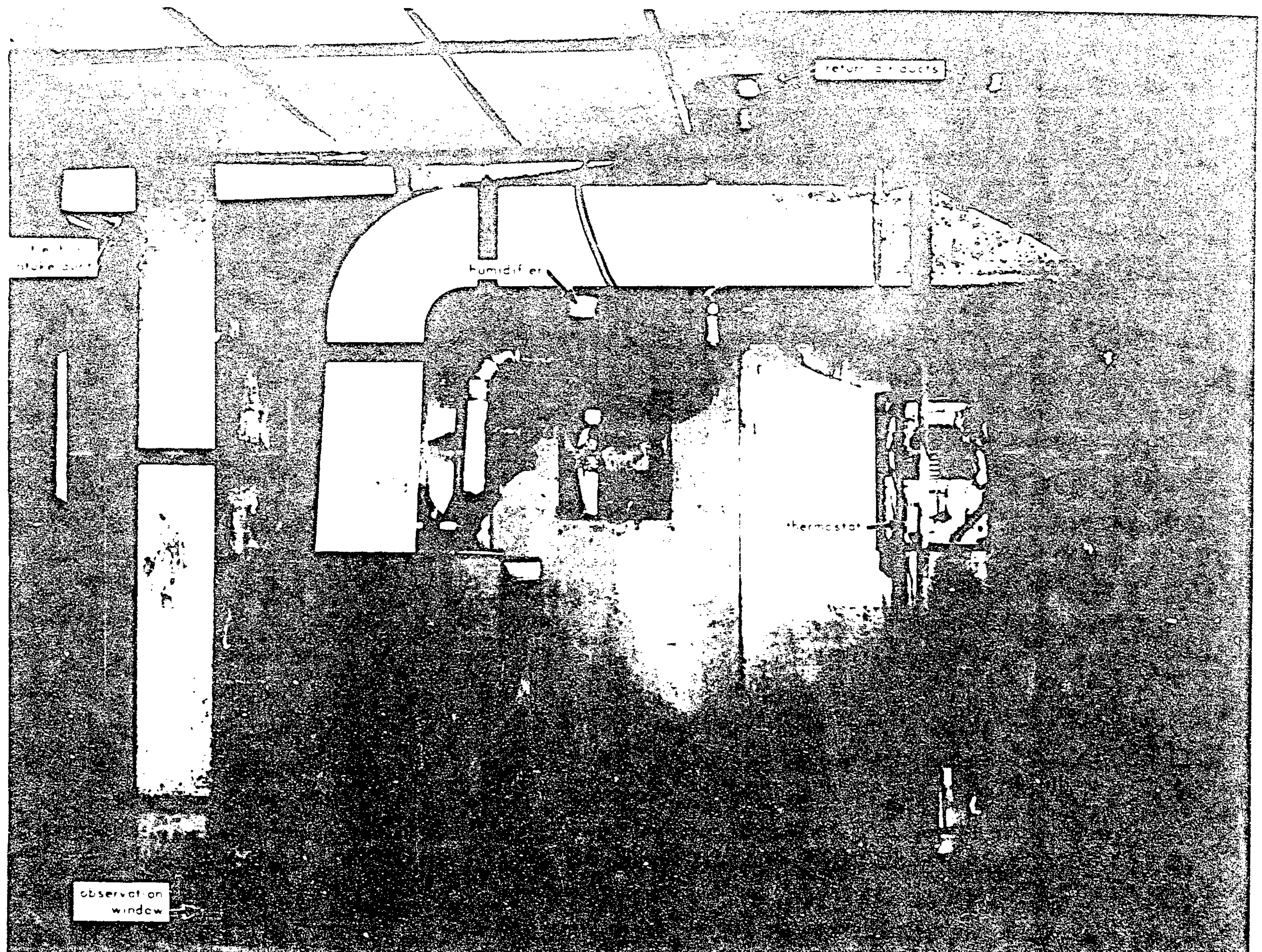



Figure 10. Overhead duct heating system.

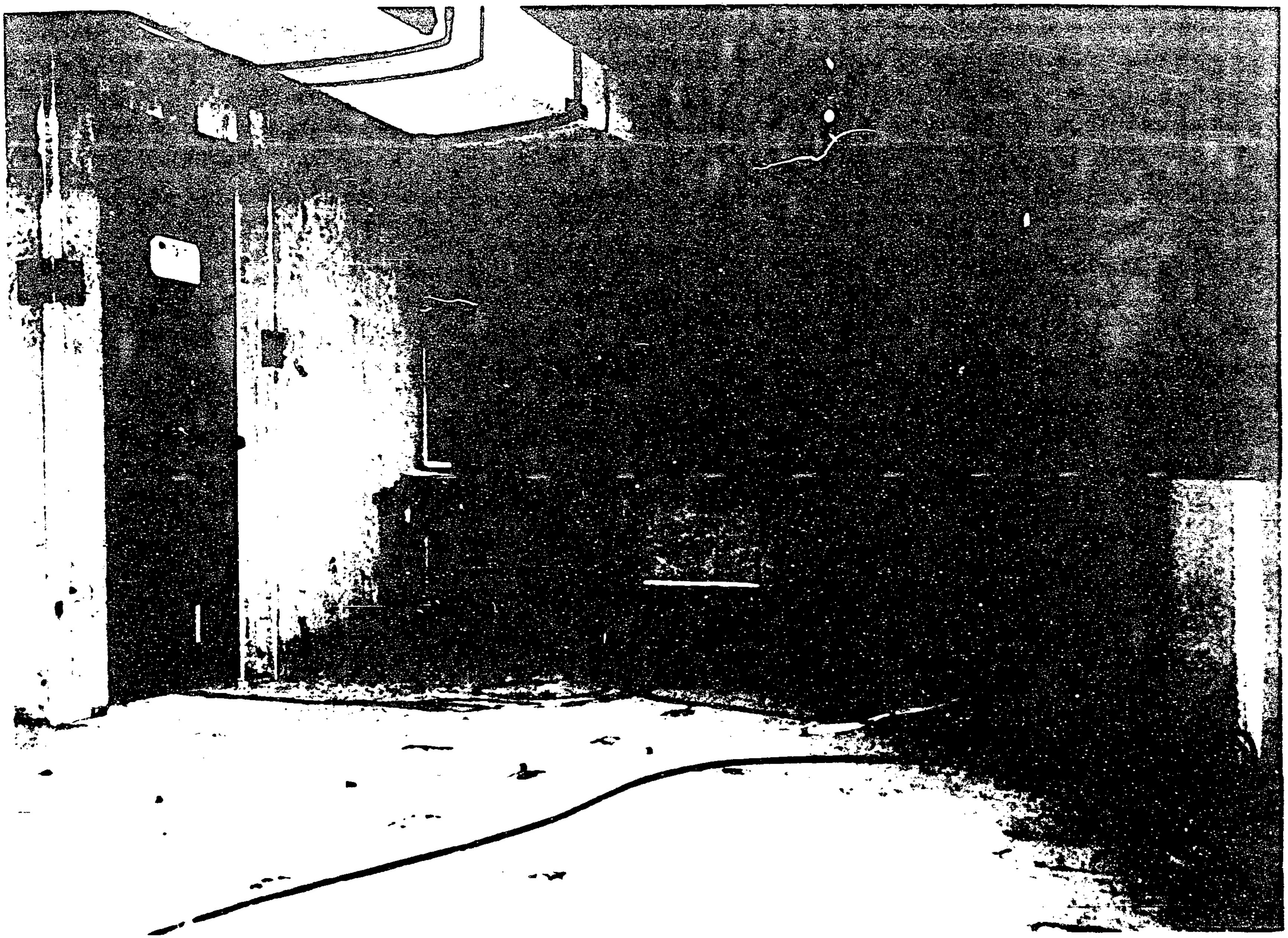


Figure 11. Overhead duct and partitioned rooms.

The controls on the furnace were standard for an oil-fired furnace with two exceptions. A remote-bulb thermostat was used in the return-air duct in place of a wall thermostat, and an identical thermostat was used in the warm-air-delivery duct to maintain a low-temperature limit on the supply air. This low-limit thermostat was required to maintain discharge-air temperatures at a comfortable level because of the addition of outside ventilation air.

The overhead duct system weighs approximately 1250 pounds and has a volume of 219 cubic feet. The weight and volume of the major components making up the system are given in Table IX.

Table IX. Weight and Cube of Overhead Duct Air-Conditioning System

| | Net Weight (lb) | Net Cube (cu ft) |
|---|---|---|
| Furnace (complete) | 400 | 47 |
| Cold-Air Return Ducts (metal) | 350 | 60 |
| Hot-Air Duct (metal) | 200 | 52 |
| Hot-Air Duct (fiberglas) | 155 | 30 |
| Roof Jack & Smoke Pipe | 70 | 19 |
| Humidifier | 30 | 3 |
| Registers & Short Duct | 30 | 4 |
| Return-Air Grill | 15 | 2 |
| | 1,250 | 217 |

## TEST CONDITIONS

The overhead duct air-conditioning system was installed in the building at the -50 F chamber temperature reached in the tests of the floor plenum system and maintained for the heat-loss tests at that temperature. A 10 x 10-inch opening was cut into the sidewall of the building to bring fresh air into the system. A 50-gallon tank was supported between the roof trusses to supply water by gravity to the duct-mounted humidifier. The partitions for the two 8 x 12-foot rooms were reinstalled, using extension pieces to make up for removal of the 5-1/2-inch-deep plenum

floor. The panels were erected in the same corner of the building, but both rooms had their 8-foot dimension along the sidewall (Figure 3). A portion of the partitioned rooms may be seen in Figure 11. It would have been desirable for the sake of uniformity to retain the same room arrangement used during the plenum heating tests, but this could not be done since the overhead duct system is designed to discharge warm air the length of the rooms. The fiberglas ceiling evaluated during the heat-loss study at -50 F was used for all of the overhead duct system tests.

The furnace blower speed was adjusted to deliver 2000 cfm, the fresh-air inlet damper was regulated to provide 500 cfm, and the 13 duct registers were balanced to deliver a proportionate amount of air. As soon as the installation was completed, the humidifier was operated at maximum capacity to establish a humidity balance. The humidifier could theoretically maintain 30 percent relative humidity with the designed air changes. At 75 F inside air temperature and 30 percent relative humidity, condensation would not be expected on the exposed interior panel surfaces but could be expected at imperfect panel joints and in other areas where furniture or other fixtures obstructed air circulation. When mixing 1 part outside air at -65 F, 90 percent relative humidity with 3 parts return air at 75 F, 30 percent relative humidity, the resultant air temperature is 40 F and the dew-point temperature is 34 F. With ideal mixing, this would not result in condensation or fogging in the return-air duct. Since mixing would not be ideal, condensation could be expected even with less moisture in the return air or at higher outside air temperatures.

To determine if condensation occurred and observe its effect, plastic windows were installed in each side of the return duct next to the furnace. By placing a light behind one of the windows, the interior of the duct could be clearly observed through the other window.

The first test was begun and the electric heaters were turned off when the temperatures in the building had stabilized and the 30 percent humidity was reached.

## INSTRUMENTATION

The instrumentation used in the overhead duct air-conditioning tests was the same as that used for the floor plenum and heat-loss studies, with one exception. The two thermocouple strings located in the rooms were recentered in the partitioned rooms to accommodate the change in orientation of the rooms. Relative humidity was measured with a hand-held battery-operated psychrometer.

## MECHANICAL PERFORMANCE

The only difficulty in starting or operating the overhead duct system occurred in the blower section of the furnace and was attributable to inexperience of the test personnel rather than to a weakness in design.

The 1-horsepower blower motor and V-belt drive were not assembled in the blower section when received. When assembling these items, the variable-pitch motor pulley was installed with a near maximum pitch adjustment. Upon starting, the blower ran for several minutes until the motor overheated and was shut off by its thermal overload protection. Considerable time was lost checking possible reasons for the overheating. It was finally realized that the large pitch diameter of the adjustable pulley resulted in mechanical overloading of the motor. The pulley was readjusted and the blower speed was set to deliver the designed air volume, and no further motor trouble occurred.

To avoid this problem, the adjustable pulley should be installed with a near minimum diameter, then adjusted to give the required blower air-delivery rate.

## HEATING PERFORMANCE

Table X shows the average temperatures attained throughout the building during the three tests of the overhead duct system. It may be seen from this table that lateral distribution of heat in the unpartitioned portion of the building varied a maximum 3 degrees among these measurements taken above ankle height (2 inches). At ankle height, the maximum average variation in heat distribution was 10 degrees. The two coldest areas were the corner across from the furnace and the center of the building. Since the system design calls for furnace installation in a utility core, no register was included for discharging air into the space directly opposite the furnace. This resulted in the low temperatures near the floor in that area. The low temperatures near the floor in the center of the building occurred for somewhat the same reason, since all the registers in the duct directly overhead discharged air away from the center toward the outside walls. Average floor surface temperature variations did not exceed 7 degrees.

Since only one temperature measurement was taken at each elevation in the rooms, a numerical analysis of heat distribution is not possible; however, observations by test personnel did not indicate inadequacies in these areas.

The individual temperatures obtained during the tests, which make up the averages shown in Table X, were very consistent. Appendix C contains a partial listing of these individual temperatures and illustrates this consistency.

Table X. Overhead Duct Tests: Comparison of Average Inside Temperatures at Different Outside Temperatures (°F)

| Area | Test Number | | |
|---|---|---|---|
| | 16 (at -50 F)[1/] | 17 (at -25 F) | 18 (at 0 F) |
| Corner Room | | | |
| Floor | 66 | 69 | 71 |
| Ankle | 73 | 74 | 74 |
| Waist | 75 | 75 | 75 |
| Shoulder | 76 | 76 | 75 |
| Ceiling | 76 | 76 | 75 |
| Inside Room | | | |
| Floor | 59 | 61 | 65 |
| Ankle | 60 | 64 | 68 |
| Waist | 70 | 71 | 73 |
| Shoulder | 74 | 73 | 74 |
| Ceiling | 78 | 74 | 75 |
| Area Facing Rooms | | | |
| Ankle | 60 | 68 | 77 |
| Waist | 70 | 76 | 79 |
| Shoulder | 76 | 77 | 79 |
| Under Building | | | |
| Under floor | -34 | -21 | -3 |
| 2 inches below | -43 | -26 | -5 |
| 12 inches below | -46 | -27 | -7 |
| Center Area | | | |
| Floor | 50 | 59 | 66 |
| Ankle | 56 | 65 | 72 |
| Waist | 72 | 74 | 76 |
| Shoulder | 76 | 77 | 78 |
| Ceiling | 76 | 77 | 78 |
| Attic | 62 | 64 | 69 |
| Roof | 56 | 58 | 65 |
| Area Facing Furnace | | | |
| Ankle | 54 | 60 | 67 |
| Waist | 72 | 74 | 76 |
| Shoulder | 76 | 77 | 80 |
| Miscellaneous | | | |
| Wall | 66 | 70 | 74 |
| Outside air 2 feet from wall | -47 | -21 | 1 |
| Heat-Flow Meter Interface | | | |
| Wall | 64 | 68 | 72 |
| Joint | 57 | 62 | 68 |
| Floor | 50 | 59 | 68 |
| Roof | 55 | 59 | 65 |

1/ Test chamber temperature

Air stratification varied at different locations in the building, as seen in Table X. Least stratification occurred in the corner room, with a variation between floor and ceiling of 10 degrees at -50 F, 7 degrees at -25 F, and 4 degrees at 0 F. In the inside room, the stratification was 6 to 9 degrees greater at each test chamber temperature. In the unpartitioned portion of the building, stratification was more severe. At the center of the building, it was 26 degrees at -50 F, 18 degrees at -25 F, and 12 degrees at 0 F. The second area of greatest stratification was the corner facing the furnace. The same explanations given for poor heat distribution in the unpartitioned areas applies to the stratification.

A good reason exists for the difference in stratification in the two rooms, which also gives rise to a solution for reducing stratification in the remainder of the building. This difference in stratification reverts to problems in balancing the heating system. The corner room, with the greater outside wall area, requires 200 cfm of hot air while the inside room requires only 125 cfm.

In adjusting the register in the corner room, it was necessary to close the dampers approximately 50 percent to obtain the 200-cfm discharge rate. In the inside room, requiring 125 cfm, a further 37 percent reduction of the opening was required. Because of the resultant damper position and the arrangement of the adjustable horizontal and vertical louvers, the air flow from the register was so dispersed that it did not carry to the opposite wall. This resulted in little air turbulence and poor mixing.

When T-5 type buildings are placed in service, a floor covering is normally used to improve wear resistance and appearance. In the temporary polar camp design[2] the floor covering consists of 20-pound asphalt-impregnated building paper, overlapped a minimum of 4 inches, covered with 1/4-inch 4 x 8-foot sheets of tempered hardboard. Such a covering, which was not used in these tests, would essentially eliminate infiltration through 31 percent of the exterior joints and reduce heat loss through the floor. These changes should result in higher floor-surface temperatures and reduced stratification.

## HUMIDIFICATION AND VENTILATION PERFORMANCE

As discussed previously, the overhead duct system tests were begun at -50 F with the duct-mounted humidifier operating at maximum capacity, which would result in a theoretical humidity of 30 percent at 75 F dry-bulb. After 12 hours of continuous operation, the relative humidity in the building had reached 27 to 30 percent, depending on where measurements were taken. Under these conditions, condensation and frost formed around the outside doors, on windows, and on leaking wall- and floor-panel joints (Figures 12, 13, and 14).

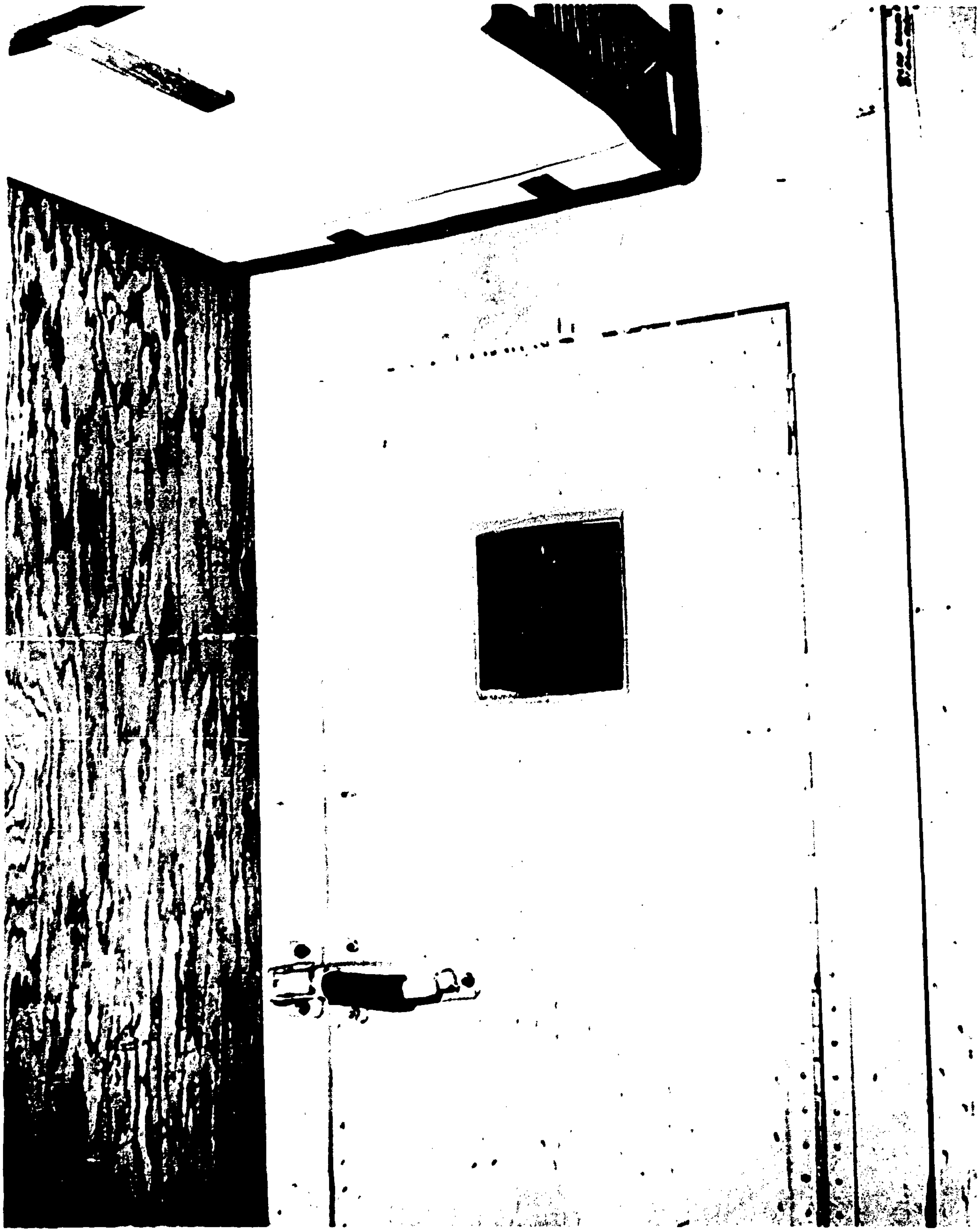


Figure 12. Frost formation around leaking door gasket at 30 percent relative humidity inside, -50 F outside.

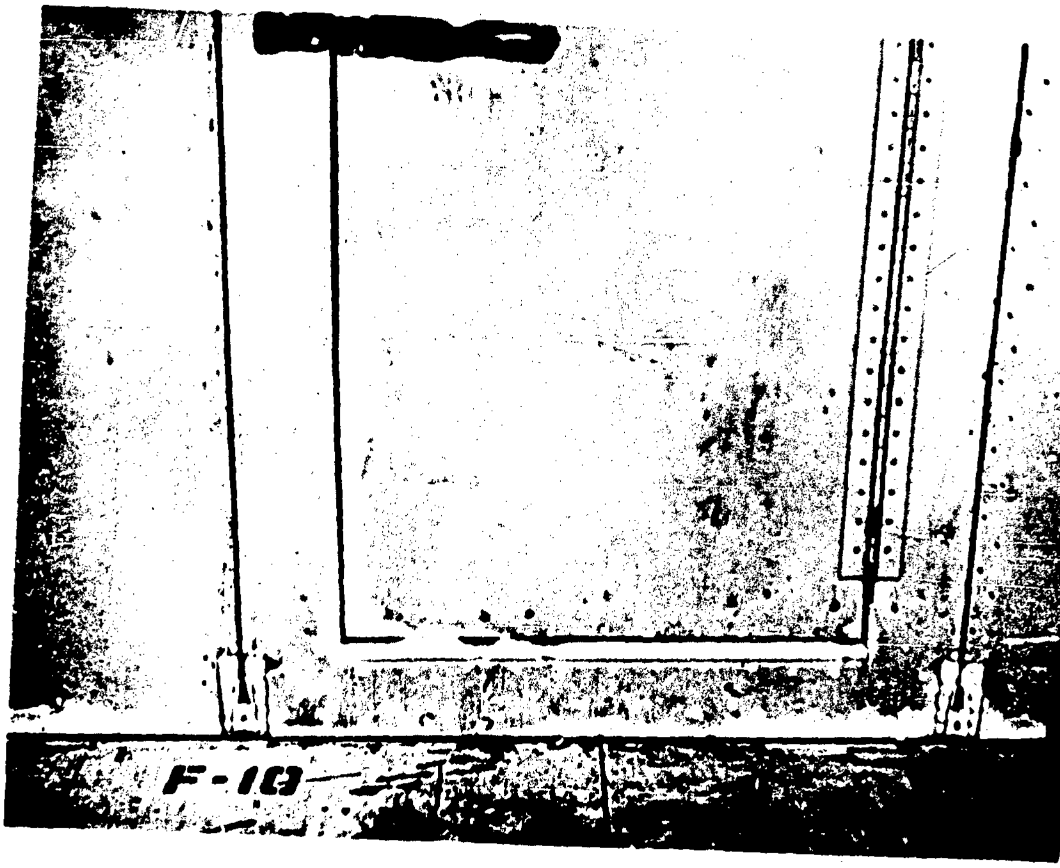



Figure 13. Frost formation around door and at base of wall panels at 30 percent relative humidity inside, -50 F outside.

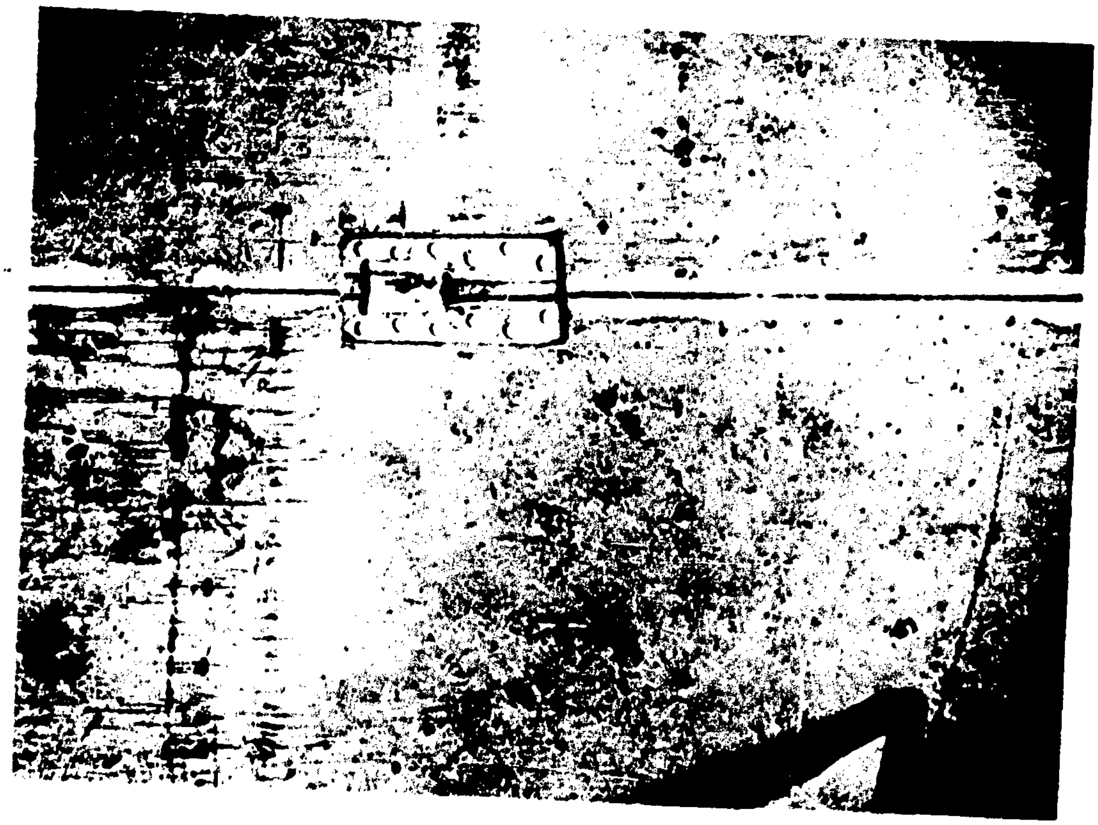


Figure 14. Frost formation on leaking floor panel joint at 30 percent relative humidity inside, -50 F outside.

The greatest area of condensation and frost developed very uniformly along the bottom 2 to 3 inches of nearly all wall panels. It would appear from this that the joint between wall and floor panels is not as effective as other joints in preventing infiltration of cold air.

The attic space above the fiberglas ceiling was inspected carefully for signs of condensation, but none were found in spite of the cooler attic air temperatures. Extra panels of fiberglas ceiling material were leaned against the walls at the start of this test to simulate furniture which might block free circulation of warm air to the walls. Considerable condensation occurred behind these panels, primarily over the joints and internal panel-framing members (Figure 15).

When these observations were completed, the humidifier was turned off and no further moisture was added to the air until the accumulated frost had melted and evaporated. The relative humidity of the air at that time averaged 22 percent. The water input to the humidifier was restricted for the remainder of the -50 F test to maintain 20 to 22 percent humidity. At these reduced humidity conditions, only minor condensation occurred around the doors, on the fresh-air intake duct, and on the fuel line for the remainder of the -50 F test. Condensation within the fresh-air, mixing duct was observed at both humidity levels; however, it was not found to have any detrimental effects on the operation of the system. No accummulation of condensate was observed within the furnace or duct.

During the -25 F and 0 F tests the humidifier was operated at maximum capacity, with only the same minor condensation on the exterior of the fresh-air intake duct and on the first few feet of fuel line. For sustained operation, the fresh-air intake duct should be of sealed double sheet-metal construction with insulation between to prevent the frost formation which makes the regulating damper difficult to operate. No condensation was observed within the mixing duct during either the -25 F or 0 F tests.

## FINDINGS

The controlled climatic heating study of the overhead duct system showed that:

1. Temperature variations 2 inches above the floor did not exceed 10 degrees.

2. At elevations above 2 inches, the maximum variation was 3 degrees.

3. Variations in floor surface temperatures did not exceed 7 degrees.

4. Air stratification between floor and ceiling was least in the partitioned portion of the building.

5. The greatest stratification occurred at the center of the building.

6. A relative humidity of 22 percent could be maintained at -50 F without condensation on window surfaces.

Figure 15. Frost formation in areas of restr,cted air circulation at 30 percent relative humidity inside, -50 F outside.

# PART V. SUMMARY

## PERFORMANCE OF HEATING SYSTEMS

The floor plenum heating system displayed excellent heat-distribution and air-stratification characteristics in the unpartitioned portion of the Modified T-5. However, the lack of control of air movement through the plenum renders it unsuitable for use in partitioned buildings. Rooms nearest the furnace, having the highest floor temperatures, were overheated while those farthest from the furnace and those with greater outside wall area were underheated.

Significant air stratification and imperfect heat distribution with the overhead duct heating system resulted in only a moderate degree of comfort. Air velocities at the face of the registers were insufficient to provide good air mixing and uniform temperatures.

## COMPARISON OF HEATING SYSTEMS

In comparing the physical characteristics of the floor plenum and overhead duct systems, it is found that the plenum system has several disadvantages:

1. No accurate cost data is available for the two systems, but an estimate of 50 to 75 percent higher for the plenum system appears conservative.

2. The shipping weight and volume of the complete plenum system are both nearly four times greater than that of the overhead duct system.

3. The minimum floor-space requirement for the two plenum system furnaces is 144 square feet, while the overhead duct system requires only 64 square feet.

4. No provisions are made for humidification or fresh-air ventilation with the plenum system.

5. Because of the H-splines between plenum sections, the floor surface is uneven, making housekeeping difficult.

## MODIFICATION OF OVERHEAD DUCT SYSTEM

As a result of the controlled-climate tests, the overhead duct system was modified to improve heat distribution and reduce air stratification. These modifications consisted of:

1. Reducing the size of the duct registers from 4 x 14 to 4 x 12 inches.

2. Specifying registers with opposed-blade dampers and with adjustable horizontal deflection vanes in front of adjustable vertical deflection vanes.

3. Providing an insulated vapor-sealed fresh-air intake duct.

4. Adding a 4 x 12-inch branch duct to supply heated air to the corner opposite the furnace.

5. Adding a supplemental 9-inch-diameter return-air duct in parallel with the two 12-inch ducts. This will reduce the pressure drop in the return-air system and provide greater flexibility in setting air-delivery rates.

The first two modifications were made to improve air mixing and distribution and the third to eliminate undesirable condensation. All are reflected in the temporary polar camp design.[2] The last two were made to improve building comfort when the air-conditioning system is installed within the structure rather than in a central utility core.

## CONCLUSIONS

1. The floor plenum heating system displayed excellent heat-distribution characteristics; however, air temperature in partitioned rooms could not be controlled. Also, the system does not provide for fresh-air ventilation and humidification, which are mandatory for maximum comfort in polar regions.

2. The overhead air-conditioning system provides fresh-air ventilation and humidification. However, its heat-distribution characteristics were not as good as those of the floor plenum heating system, and stratification in the inhabited zone was higher than desirable.

3. Of the two systems tested, the overhead duct system more nearly meets the exacting requirements for comfort-conditioning polar structures. Stratification can be reduced and heat distribution can be improved by increasing register discharge velocities.

## REFERENCES

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2. U. S. Naval Civil Engineering Laboratory. Technical Report R-288, A Temporary Polar Camp, by G. E. Sherwood. Port Hueneme, California, 26 March 1964.

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4. Russell J. Bartell. "A Nuclear Power Plant in Antarctica," Navy Civil Engineer, October 1962.

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## Appendix A

## THEORETICAL HEAT-LOSS CALCULATION

**Design Conditions:**

| | |
|---|---|
| Outside | -50 F |
| Inside | 75 F |
| $\Delta T$ | 125 Degrees |

Wind velocity in test chamber - 2 mph

**Heat-Transmission Factors:**

| | | | | | |
|---|---|---|---|---|---|
| Roof & walls | 0.0930 | x | 125 | = | 11.6 Btu/sq ft |
| Floor | 0.0920 | x | 125 | = | 11.5 Btu/sq ft |
| Framing members | 0.217 | x | 125 | = | 27.2 Btu/sq ft |
| Windows | 0.41 | x | 125 | = | 51.2 Btu/sq ft |

**Heat Loss:**

Area of framing members in walls, floor, and roof represent 20 percent of the total areas.

Walls:

| | | |
|---|---|---|
| Wall area | 2 (56 x 10) + 2 (28 x 10.66) = | 1717 sq ft |
| Area of wall framing | 1717 x 0.20 = | 343 sq ft |
| Window area | 3.36 sq ft x 18 = | 60 sq ft |
| Net insulated wall area | 1314 sq ft x 11.6 = | 15,250 Btuh |
| Wall framing area | 343 sq ft x 27.2 = | 9,320 Btuh |
| Window area | 60 sq ft x 51.2 = | 3,070 Btuh |
| Total loss through walls | | 27,640 Btuh |

Roof:

| | | | | | | |
|---|---|---|---|---|---|---|
| Roof area | 28 x 56 | = | 1568 sq ft | | | |
| Roof framing area | 1568 x 0.20 | = | 314 sq ft | x 27.2 | = | 8,540 Btuh |
| Net insulated roof area | | | 1254 sq ft | x 11.6 | = | 14,550 Btuh |
| Total loss through roof | | | | | | 23,090 Btuh |

Floor:

| | | | | | | |
|---|---|---|---|---|---|---|
| Floor area | 28 x 56 | = | 1568 sq ft | | | |
| Roof framing area | 1568 x 0.20 | = | 314 sq ft | x 27.2 | = | 8,540 Btuh |
| Net insulated floor area | | | 1254 sq ft | x 11.5 | = | 14,430 Btuh |
| Total loss through floor | | | | | | 22,970 Btuh |

Total Heat Loss Through Building Shell:

| | |
|---|---|
| Walls | 27,640 Btuh |
| Roof | 23,090 Btuh |
| Floor | 22,970 Btuh |
| Total | 73,700 Btuh |

## Appendix B

# SUMMARY OF TEMPERATURES (°F) OBTAINED WITH FLOOR PLENUM HEATING SYSTEM

Average of 18 Readings Taken During a 2-Hour Period

| Area | Test Number | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 (at 0 F)[1] | 2 (at 0 F) | 3 (at 0 F) | 4 (at 0 F) | 5 (at -25 F) | 6 (at -25 F) | 7 (at -25 F) | 8 (at -25 F) | 9 (at -50 F) | 10 (at -50 F) | 11 (at -50 F) | 12 (at -50 F) | 12A (at -50 F) |
| Corner Room | | | | | | | | | | | | | |
| Floor | 67 | 75 | 65 | 76 | 63 | 76 | 63 | 76 | 67 | 78 | 68 | 81 | 94 |
| Ankle | 65 | 72 | 63 | 74 | 60 | 74 | 58 | 72 | 60 | 74 | 62 | 77 | 91 |
| Waist | 67 | 74 | 65 | 77 | 63 | 79 | 61 | 77 | 62 | 80 | 64 | 81 | 92 |
| Shoulder | 67 | 74 | 65 | 77 | 63 | 79 | 61 | 78 | 63 | 80 | 64 | 82 | 92 |
| Ceiling | 66 | 74 | 65 | 75 | 61 | 78 | 59 | 75 | 60 | 78 | 62 | 79 | 89 |
| Inside Room | | | | | | | | | | | | | |
| Floor | 81 | 88 | 83 | 84 | 85 | 86 | 82 | 84 | 84 | 84 | 85 | 86 | 88 |
| Ankle | 76 | 82 | 78 | 80 | 79 | 81 | 75 | 78 | 76 | 78 | 78 | 80 | 85 |
| Waist | 75 | 81 | 77 | 78 | 77 | 79 | 74 | 76 | 75 | 76 | 77 | 78 | 84 |
| Shoulder | 75 | 81 | 77 | 78 | 77 | 79 | 74 | 76 | 75 | 72 | 77 | 78 | 84 |
| Ceiling | 74 | 81 | 76 | 78 | 77 | 79 | 69 | 73 | 70 | 75 | 75 | 76 | 83 |
| Area Facing Rooms | | | | | | | | | | | | | |
| Ankle | 78 | 75 | 73 | 73 | 74 | 73 | 75 | 74 | 75 | 74 | 75 | 74 | 75 |
| Waist | 78 | 76 | 74 | 74 | 74 | 74 | 75 | 74 | 74 | 74 | 74 | 74 | 76 |
| Shoulder | 78 | 76 | 75 | 74 | 74 | 73 | 74 | 74 | 74 | 74 | 74 | 74 | 76 |
| Under Building | | | | | | | | | | | | | |
| Under Floor | 7 | 9 | 8 | 6 | -9 | -13 | -12 | -13 | -26 | -28 | -34 | -31 | -34 |
| 2 inches below | 2 | 3 | 4 | 1 | -17 | -20 | -19 | -21 | -38 | -39 | -43 | -42 | -44 |
| 12 inches below | 2 | 4 | 3 | 1 | -18 | -20 | -21 | -21 | -41 | -42 | -43 | -44 | -45 |

1/ Test chamber temperature

Average of 13 Readings Taken During a 2-Hour Period

| Area | Test Number | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 (at 0 F) 1/ | 2 (at 0 F) | 3 (at 0 F) | 4 (at 0 F) | 5 (at -25 F) | 6 (at -25 F) | 7 (at -25 F) | 8 (at -25 F) | 9 (at -50 F) | 10 (at -50 F) | 11 (at -50 F) | 12 (at -50 F) | 12A (at -50 F) |
| Center Area | | | | | | | | | | | | | |
| Floor | 2/ | 2/ | 80 | 78 | 78 | 76 | 77 | 75 | 76 | 74 | 75 | 73 | 73 |
| Ankle | | | 78 | 78 | 77 | 77 | 78 | 75 | 75 | 74 | 75 | 74 | 73 |
| Waist | | | 79 | 79 | 78 | 77 | 78 | 77 | 76 | 75 | 75 | 74 | 75 |
| Shoulder | | | 76 | 79 | 78 | 78 | 78 | 77 | 76 | 75 | 75 | 75 | 77 |
| Ceiling | | | 76 | 76 | 74 | 74 | 74 | 74 | 77 | 71 | 71 | 70 | 73 |
| Attic | | | 69 | 71 | 66 | 67 | 65 | 66 | 63 | 63 | 62 | 62 | 69 |
| Roof | | | 66 | 66 | 60 | 61 | 60 | 60 | 56 | 56 | 55 | 54 | 59 |
| Area Facing Furnace | | | | | | | | | | | | | |
| Ankle | | | 77 | 77 | 76 | 77 | 77 | 76 | 74 | 74 | 73 | 73 | 74 |
| Waist | | | 78 | 78 | 77 | 77 | 77 | 76 | 75 | 74 | 74 | 74 | 75 |
| Shoulder | | | 78 | 78 | 78 | 78 | 77 | 77 | 76 | 76 | 75 | 75 | 76 |
| Miscellaneous | | | | | | | | | | | | | |
| Wall | | | 72 | 73 | 69 | 69 | 69 | 69 | 65 | 64 | 65 | 64 | 67 |
| Outside air 2 feet from wall | | | 4 | 4 | -23 | -23 | -20 | -19 | -48 | -50 | -50 | -47 | -44 |

1/ Test chamber temperature
2/ Chart drive failed

Apper C

## INDIVIDUAL TEMPERATURE MEASUREMENTS RECORDED DURING OVERHEAD DUCT HEATING SYSTEM TESTS AT -50 F

| Time | Corner Room | | | | | Inside Room | | | | | Area Facing Rooms | | | Under Building | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Floor | Ankle | Waist | Shoulder | Ceiling | Floor | Ankle | Waist | Shoulder | Ceiling | Ankle | Waist | Shoulder | Under Floor | 2 In. Below | 12 In. Below |
| 2400 | 65 | 72 | 74 | 74 | 75 | 59 | 60 | 70 | 74 | 79 | 59 | 70 | 78 | -35 | -43 | -45 |
| 0008 | 66 | 74 | 76 | 76 | 76 | 59 | 60 | 70 | 73 | 76 | [illegible] | 70 | 76 | | | |
| 0016 | 65 | 73 | 76 | 77 | 78 | 59 | 61 | 70 | 75 | 77 | 60 | 71 | 74 | | | |
| 0024 | 65 | 72 | 74 | 75 | 76 | 59 | 60 | 70 | 74 | 79 | 59 | 70 | 78 | | | |
| 0032 | 66 | 74 | 75 | 75 | 74 | 59 | 60 | 70 | 73 | 77 | 60 | 70 | 76 | -34 | -43 | -45 |
| 0040 | 66 | 74 | 76 | 77 | 78 | 59 | 61 | 70 | 75 | 76 | 61 | 71 | 73 | | | |
| 0048 | 65 | 72 | 74 | 75 | 76 | 59 | 60 | 70 | 74 | 80 | 59 | 71 | 78 | | | |
| 0056 | 66 | 73 | 74 | 75 | 75 | 59 | 60 | 70 | 73 | 77 | 60 | 70 | 76 | | | |
| 0104 | 66 | 74 | 76 | 77 | 78 | 59 | 61 | 70 | 75 | 75 | 61 | 70 | 74 | -33 | -44 | -47 |
| 0112 | 65 | 72 | 75 | 76 | 77 | 59 | 60 | 70 | 75 | 80 | 59 | 71 | 78 | | | |
| 0120 | 66 | 72 | 74 | 74 | 75 | 59 | 60 | 70 | 73 | 78 | 60 | 70 | 76 | | | |
| 0128 | 66 | 73 | 76 | 77 | 78 | 59 | 60 | 70 | 74 | 75 | 61 | 70 | 75 | | | |
| 0136 | 65 | 73 | 76 | 76 | 77 | 59 | 61 | 70 | 75 | 80 | 50 | 70 | 76 | -34 | -43 | -46 |
| 0144 | 65 | 72 | 73 | 74 | 75 | 59 | 60 | 70 | 73 | 78 | 59 | 70 | 78 | | | |
| 0152 | 66 | 74 | 76 | 77 | 76 | 59 | 60 | 70 | 73 | 75 | 60 | 70 | 75 | | | |
| 0200 | 65 | 72 | 76 | 76 | 77 | 59 | 60 | 70 | 75 | 79 | 59 | 71 | 75 | -33 | -40 | -46 |

| Time | Center Area | | | | | | | Area Facing Furnace | | | Miscellaneous | | Heat-Flow Meter Interface Temp. | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Floor | Ankle | Waist | Shoulder | Ceiling | Attic | Roof | Ankle | Waist | Shoulder | Wall | Outside Air 2 ft fr Wall | Wall | Joint | Floor | Roof |
| 2400 | 50 | 58 | 70 | 72 | 72 | 60 | 55 | 54 | 70 | 74 | 66 | -46 | 64 | 57 | 51 | 55 |
| 0010 | 50 | 56 | 72 | 73 | 73 | 62 | 56 | 55 | 70 | 75 | 66 | -48 | 64 | 57 | 50 | 52 |
| 0020 | 50 | 54 | 72 | 78 | 78 | 62 | 56 | 52 | 72 | 78 | 66 | -50 | 64 | 56 | 50 | 54 |
| 0030 | 50 | 56 | 72 | 78 | 78 | 64 | 56 | 54 | 73 | 78 | 66 | -46 | 64 | 58 | 50 | 55 |
| 0040 | 50 | 56 | 72 | 76 | 76 | 62 | 56 | 54 | 72 | 76 | 77 | -46 | 64 | 58 | 50 | 55 |
| 0050 | 50 | 56 | 72 | 76 | 76 | 62 | 55 | 54 | 72 | 75 | 66 | -46 | 64 | 58 | 50 | 55 |
| 0100 | 50 | 57 | 70 | 74 | 74 | 61 | 56 | 54 | 72 | 74 | 66 | -48 | 64 | 58 | 50 | 55 |
| 0110 | 50 | 58 | 70 | 73 | 73 | 61 | 56 | 54 | 70 | 72 | 66 | -49 | 64 | 57 | 50 | 55 |
| 0120 | 50 | 56 | 74 | 76 | 76 | 62 | 56 | 54 | 72 | 76 | 66 | -48 | 65 | 57 | 50 | 55 |
| 0130 | 50 | 56 | 74 | 79 | 78 | 63 | 56 | 52 | 74 | 78 | 67 | -46 | 65 | 58 | 50 | 55 |
| 0140 | 50 | 56 | 73 | 78 | 78 | 63 | 56 | 53 | 74 | 78 | 66 | -48 | 65 | 58 | 50 | 55 |
| 0150 | 50 | 55 | 72 | 77 | 77 | 62 | 56 | 54 | 72 | 76 | 66 | -46 | 64 | 58 | 50 | 55 |
| 0200 | 50 | 55 | 72 | 76 | 76 | 61 | 55 | 54 | 72 | 76 | 66 | -49 | 64 | 57 | 50 | 55 |